UC-NRLF
B 4 208 486

Muscles of the Eye

ROGERS

BERKELEY
LIBRARY
UNIVERSITY OF
CALIFORNIA

FROM THE OPTOMETRIC LIBRARY
— OF —
MONROE JEROME HIRSCH

1041

Jacques Lemmonski
3606 Bosworth ave.

THE LIBRARY
OF
THE UNIVERSITY
OF CALIFORNIA

GIVEN WITH LOVE TO THE
OPTOMETRY LIBRARY
BY
MONROE J. HIRSCH, O.D., Ph.D.

THE MUSCLES *of the* EYE

A Treatise on the Optical Functions of the Muscles in Normal and Abnormal States

By
GEORGE A. ROGERS

Illustrated

Published by the Professional Press, Inc., Chicago, Ill.

WW 100
S5

OPTOMETRY

Copyrighted,
1922.

RE731
R6
1922
OPTO

TABLE OF CONTENTS

Chapter I - - - - - - - - - - 7
Normal Eyes—Muscle Functions—Forms of Muscles—Classification—Optical Functions—Nervous Control—Motor-Nerve Centres—System of Control.

Chapter II - - - - - - - - 15
Pupillary Control—Dilation of the Pupil—Motor-Nerve Stimulus—Pupillary Reflex—Tinted Lenses—Magnified Pupil—Pupillary Discs—Pupillary Distance.

Chapter III - - - - - - - - 23
Refraction Control—Dynamic Refraction—Ciliary Action—The Ciliary Body—Motor-Nerve Control—Sensory Initiation—Motor-Nerve Ganglia—Amplitude of Accommodation—Demand for Accommodation—Presbyopia—Neurometry of Accommodation—The Time Element.

Chapter IV - - - - - - - - 41
Abnormal Structures—Functional Effects—Myopia—Inductive Effects—Auxiliary Effects—Far and Near Points—Presbyopia—Hyperopia—Further Examination—Finding Hyperopia—Subjective Findings — Ciliary Eccentricities — Repression—Astigmatism—Hyperopic Induction.

Chapter V - - - - - - - - - 62
Vision—The Retina—Visual Acuity—Foveal Vision—Fixation—Visual Axis—Indirect Vision—Cardinal Points—The Sensory Tracts—Binocular Single Vision—Normal Violation of the Rule—Stereoscopic Vision—Image Displacements—Visual Deception.

Chapter VI - - - - - - - - 82
Axillary Control—Mountings and Muscles—Binocular Pairs—The Medial Planes—Primary Position—Functional Activities—Normal Versions—Version Coördinates—Version Characteristics—Version Tests—Version Anomalies — Homophorias — Version Exercises — Oculo-Didactics—Character Studies.

Chapter VII - - - - - - - - **100**
Duction of the Eyes—Contest of Functions—Normal Ductions—The Meter Angle—The Object Distance—Convergence vs. Adduction—Normal Near Vision—Fixation of Object—Duction Muscles—Nerve Control—Duction Tests—Reflex Influences.

Chapter VIII - - - - - - - - **122**
Muscular Imbalance—The Homophorias—The Heterophorias—Direction of Imbalance—Motor-Nerve Controls—Induction Influence—Intrinsic Inductions—Extrinsic Combinations—Extrinsics with Intrinsics—Functional Neutrality—Vertical Influences—Near Vision Balance—The Cyclophorias.

Chapter IX - - - - - - - - **140**
Static Phorometry—The Target—Device and Target—Binocular Test—Diagnosis of Imbalance—Esophoric Measurement—Exophoric Measurement—Exophoric Induction—Functional Equilibrium—Vertical Tests—Muscle Neutralization—Prism Measurement—Oblique Muscle Tests.

Chapter X - - - - - - - - **165**
Dynamic Phorometry—Muscle Tests for Near—Addition for Near—Special Dynamic Methods—Prism and Cover Test—Motion Tests—Rotating Prism Test—Dynamic Skiametry Test—Dioptric Equivalents.

Chapter XI - - - - - - - - **185**
Muscle Exercise—Methods of Exercise—The Natural Method—Artificial Methods—Trial Case Devices—Risley Rotary Prisms—Rotary Cylinders—The Amblyoscope—The Phorometer—Genothalmic Refractor—De Zeng Phoro-Optometer—The Woolf Ski-Optometer—General Remarks.

FOREWORD

THE following treatise on the ocular muscles represents the thought and work of several years, concentrated upon this important subject, which is now put into usable shape and offered by the author to the profession of optometrists of the country as a contribution to their rapidly growing efficiency in the knowledge and practice of their profession. It has long been apparent to the student, and still more pressingly evident to the practitioner of optometry that a working knowledge of refraction of the eye involves more than an acquaintance with the laws and phenomena of pure optics. He must understand the dynamic mechanism by which a pair of eyes are brought into conformance with these laws, and produce these phenomena. And, as all the dynamic phases of vision are brought about by means of ocular muscles, controlled through their nerve supply, this is equivalent to saying that he must have a working knowledge of the muscles of the eyes and their functioning, in both normal and abnormal states, at least so far as their optical relations are concerned.

Ocular muscle functions, and their anomalies, admittedly constitute one of the most vexed and troublesome set of problems in the field of refraction. More confusion has gathered around them than around any other subject in the optometrist's mental kit. It may be added that more foolish theories have been propounded, and more unsound practices advocated and indulged in, than one cares to dwell upon. Yet the matter lends itself, like every other physiologic problem, to clear and logical solution, if only it be approached by clear and logical thinking. It is to the clearing away of the confusion, and to the straightening of the crooked paths which have led into such hopeless entanglement that the author has addressed himself in this book.

The only way to find the right path, after having missed the road is to go back to the starting point and start again. This is the course which the author has pursued. Every detail of organic

structure which has a direct bearing upon the optical functioning of the eyes is carefully gone over. Step by step the mechanism and functioning of these structures are examined and explained. Several new and (as far as the author is aware) original explanations are offered for hitherto unexplained phenomena; all of which, however, it is believed are vindicated and borne out by the facts in the case. Throughout, the practical aspect of the matter which primarily interests the optometrists, namely, the test whether the function operates normally or not, is made paramount.

In offering this fruit of his thought and labor to the profession, the author has but one motive—to prepare the way of the optometrist and to make his paths straight. Its task will have been fulfilled, its purpose accomplished, when every practicing optometrist shall, by its aid, intelligently explore and correct the muscle function of every patient as an integral part of refraction.

GEO. A. ROGERS.

May 1, 1922, Chicago, Ill.

CHAPTER I.

Normal Eyes.

To discharge their visual offices most efficiently, the eyes must have certain normal qualities and powers, some of them of a structural character, and others functional. These normal qualities are,

I. *Structural,*

1. Normal transparency of the dioptric media.
2. Normal static refraction, emmetropia.
3. Normal muscular balance, orthophoria.

II. *Functional,*

4. Normal action of ocular muscles.
5. Normal acuity of vision.

Corresponding to the above list of normal qualities, there are defects tending to impair the efficiency of the eyes as visual organs. Defects of structure often disturb or disarrange the functional activities, but are structural defects only. A functional defect is not of this kind, but an abnormality of action.

Defects relating to the first and last qualities in the above list tend to impair vision but are not correctable with lenses. Hence, opacities of the media and subnormal acuity of vision are not defects that come within the province of optometry or optometric practice, although the optometrist may be able, in some cases, to ameliorate these conditions. He should observe them, and take them into account in making visual tests, and also in prescribing lenses for defects that may be corrected by them.

Muscular Functions.

A muscle has but one primary function. It can contract. The relaxation of a muscle is its passive subsidence, after contraction, and is not to be considered as a function.

As a muscle is composed of many thread-like fibers, extending in the same direction as the muscle of which they are a part, contraction shortens all of these fibers and draws the extremities of the muscle toward each other. It therefore produces always a pulling effect. A muscle cannot be made effective for pushing, except indirectly.

But a muscle is not self-contracting. To contract it requires the stimulus of a motor nerve; and the stimulus to the muscle through the motor nerve may be voluntary or involuntary. Most of the activities of the ocular muscles are of the involuntary class; and these sometimes have to act in opposition to the natural voluntary activities.

What the effects of a muscular contraction are depends upon the arrangement of the muscular fibers, or the form of the muscle, and its attachments to other tissues. To produce an optical effect, or to function optically, the muscle must operate tissues having optical functions, for a muscle has no intrinsic optical quality or function.

We must therefore look to the tissues that an ocular muscle operates for its optical effects or functioning.

Forms of Muscles.

The ocular muscles are of three varieties of form, adapted to the offices or functions to which they are assigned. These are,

1. The *circular* or sphincter form.
2. The *radial* or dilator form.
3. The *straight* or longitudinal form.

The circular form is a ring-like arrangement of the fibers around an aperture of some sort. Contraction of the muscle constricts or tends to reduce the size of the aperture. Hence sphincters.

The radial form consists of straight fibers extending out from the margins of an aperture. Contraction of these fibers tends to enlarge or dilate the aperture from which they radiate. Hence dilators.

These two sets of muscles, sphincters and dilators, when combined in one tissue, are antagonistic to each other, but co-operate in controlling the size of the aperture.

The straight or longitudinal form, when not radially arranged, consists of a single muscle, extending from one tissue to another, and attached, at its extremities, to both by tendons. Usually one of the tissues is more firm, stable or immobile than the other, so that contraction of the muscle draws the less stable tissue toward the more stable one to which the other extremity of the muscle is anchored. This produces a movement, perhaps a rotation, of the mobile tissue in that direction.

Classification.

The ocular muscles are naturally divided, according to their location, into two main groups or divisions, the intrinsic and the extrinsic muscles. As indicated by these terms, the intrinsics lie within the eye, and the extrinsics are outside of it, but attached to it at one extremity.

The intrinsic muscles consist of two classes, operating different but associated functions, and the muscles of each of these two classes have the sphincter-and-radial arrangement of muscular fibers, indicating antagonistic co-operation or co-ordination in exercising control. The extrinsic muscles are so placed and attached that their contraction rotates the eye in its orbit, either singly or both eyes at once, and in the same or in opposite directions.

Optical Functions.

The optical functions of the ocular muscles, intrinsic and extrinsic, are as follows:

I. *Intrinsic,*

1. The iris muscles control the size of the pupillary aperture for the admission of light into the eye.
2. The ciliary muscles control the increase and decrease of convexity of the crystalline lens.

II. *Extrinsic,*

3. Muscles that control the direction of the visual axis of each eye, and the relative direction of both axes.

Although a muscle has but the one primary function, by its contraction it moves tissues into different relative positions, and these are effective as optical functions of the eyes.

Co-operative Antagonism.

In all of the "settings" of the ocular muscles the principle of co-operative antagonism, or antagonistic co-operation, is observed.

FIGURE 1.

Different arrangements of (M) muscular fibers in ocular muscles for different functions: 1, (S) Sphincter and (R) Radial arrangement; 2, Fan-shaped arrangement (A, anchor; M, muscles); 3, Longitudinal, Meridianal or Lineal arrangement (T, tendons; M, muscles, A, anchor).

Control requires that a function should operate in either direction, or in opposite directions, so that one may check the other, or either may undo what the other has done, leaving nothing to natural forces, such as the force of gravity, elasticity, etc. This arrangement alone gives complete muscular control of a function.

As a single muscle can *pull,* but can't *push,* the antagonistic pairing of opposing muscles is necessary to provide control. In the iris this arrangement is fully provided for and recognized. In the ciliary there is a similar arrangement of muscular antagonists, but the full details of their antagonistic co-operation are wanting, though the need of it is apparent, and like the iris may soon be discovered. It is optically, and therefore physiologically certain.

The extrinsic muscles of each eye are in antagonistic pairs, rotating the eye in opposite directions. Binocularly, the two eyes may be rotated together in the same direction, and this is a natural

and voluntary movement, employing co-ordinate pairs of muscles. But they may also be rotated, by the same muscles, but in different pairs, in opposite directions, and the last are antagonistic to the first.

Nervous Control.

But back of the muscle there is a motor nerve, and back of this there is a ganglionic nerve-center, endowed with the power to receive and interpret sensory demands that are brought to it by sensory nerves, and to generate and transmit motor-nerve stimulus to the muscles that are required to act to allay a sensory irritation. The ganglionic center may be the brain itself, or some outlying station, delegated to exercise control over a particular function.

Brain directed motor-nerve force, which is exercised or not, at will, is voluntary. But the powers exercised by an outlying ganglionic nerve-center and confined to a specific function, are involuntary. An involuntary action of this kind is termed a "reflex action" since the sensory message, before it can reach the brain, is intercepted and reflected back as motor-nerve stimulus to the muscle required to act. It not only relieves the brain power of responsibility, but discharges it with a promptness and fidelity that the mind faculties would be unable to exercise, for it *feels* exactly what is wanted, and supplies it.

The intrinsic muscles of the eye, both those of the iris and the ciliary, are exercised by reflex action. Binocularly, the co-ordinate movements of the eyes, and the exercise of the muscles in co-ordinate pairs, to rotate the eyes in the same direction, is a voluntary action. But the exercise of the same muscles in antagonistic pairs, to rotate the eyes in opposite directions, is an involuntary or reflex action.

Motor-Nerve Centers.

The location of the ganglionic nerve centers that exercise involuntary control over muscles, is like the locating of stars and constellations in the firmament. Much may be known, but there are still undiscovered activities to account for. One of these may be the action of the ciliary muscles to control the convexity of the crystalline lens.

Optometrists are not anatomists nor surgeons. Their observations are in optical effects, and by them they judge the function and

the potentiality of a muscle to discharge that function efficiently. If it cannot, it is either because the load is too heavy or the control is too weak. They take off the load, when it is over loaded, by lenses, or strengthen the function by enforced exercise, if it is abnormally weak. For either of these corrective measures, optometrists employ lenses only, but they are the best, and often the only corrective agents.

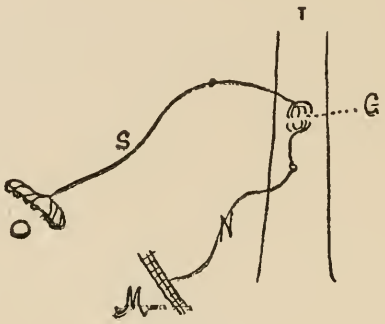


FIGURE 2.

Elements of Reflex Arch: O, objective point of contact and irritation; S, sensory nerve from O to G; G, ganglionic nerve-center, direct source of stimulation; N, motor nerve from G to M; M, muscle stimulated by N; T, trunk line of general nervous system.

System of Control.

In the operation of the muscular functions of the eyes by reflex action, the system of control is not unlike that of the operation of a continental telegraph or telephone system, in which a central office exercises supreme command, but delegates the minor details to outlying stations or exchanges. In some respects these exchanges resemble the "tower man" of a great railway, operating the switches under the direct supervision of the "train dispatcher" but functioning individually for local traffic over the line.

Nor is the modern "wireless" means of communication left out of the scheme, for light arrives at its destination on no material wires, but wings its ways through ether to the air, and through the air to a sensitive instrument that records what it has to say of the world around, so that the messages from objects to the eye are registered upon the sensitive field of the retina, from which point

they proceed by material conveyors, the sensory nerves, to the ganglionic motor-nerve centers, where their messages are received and interpreted, and from which the necessary stimulus for muscular action is sent out.

The eye is the instrument that transcribes the messages brought to it by wireless, which is in the universal language of physical science, that the brain physiologically reads and interprets into action. Does it seem as though the exercise of these physiologic, neurologic and psychologic functions or powers were "copied" after the telegraph, telephone or railway systems; or that the latter are weak imitations of the former powers that have been exercised by man since his creation? And at the present time, which is the most perfect in its operation? And whence comes the neuro-sensory and neuro-motive force that operates the human system but from dynamos that are embraced within and concealed by its various tissues, as the operation of the eye is?

The only apparent superiority of the materially constructed artificial system is its perpetuity, which is limited of course, but may be renewed, repaired, undergo substitution of parts, but must be constantly charged and recharged with the electric current, provided by the human machine, to keep it in operation. Without the latter it dies even more certainly and quickly; and without man to observe its functioning, as well as to direct its operation, of what consequence would it all be?

So, it would seem, that whatever credit we may give ourselves, for scientific discovery and invention, nature has anticipated us by some millions of years, and provided a model for us to follow, a "master machine" for us to copy. We will find this to be the case with the lesser details of the human mechanism, as the dioptric media of the eye, constructed in the lens form. Their transparency exceeds that of the finest optical material or glass that we can produce. And, without the eye as the final optical mechanism, what purpose would all of our lenses serve? We have no natural bi-focal, but the power of accommodation, while active, makes it unnecessary.

As to the principle of the bifocal lens, or rather of the wonderful Kryptok variety of it, the model for that is in the eye, for the

crystalline lens is countersunk between media of less optical density and has the excessive curvature required to give it a special lens action in addition to the other lens elements that enclose it. But it has, by the exercise of accommodation, the function of increasing that curvature and power, which no Kryptok possesses. In the eye you have modern optical and optometric science, as it were, in a nutshell.

CHAPTER II.

Pupillary Control.

This is a function that is exercised directly by the muscles of the iris, an opaque pigmented or colored screen directly back of the cornea, from whose posterior surface it is separated by a space of about 2½ millimeters.

It lies, or is suspended, just forward of the crystalline lens, so that its inner margins, surrounding a central round aperture, the pupil, rest against the anterior capsule of the lens. The transparent aqueous humor fills the space between it and the cornea, and also the space that remains between it and the outer margins of the lens and the suspensory ligament. It is an appendage of the ciliary body, or of the choroid tunic, of which the ciliary body is a feature.

Its most important feature, besides its opacity and color, is the round aperture in its center, the pupil, through which light is admitted into the inner eye. Normally of about 4 mm. in diameter, the size of the pupil may be reduced or increased by the means of muscles, arranged in the sphincter-and-radial form. The sphincter muscles are located in the margin of the iris surrounding the pupil. Their contraction constricts or reduces the size of the pupil; while the radial muscles extend from the sphincter to the outer borders of the iris, and their contraction enlarges or dilates the pupil.

The antagonistic arrangement of these muscles indicates their opposition to each other, and yet they co-operate harmoniously for the control of the size of the pupillary aperture. When the sphincters contract the radials relax, and vice versa, so that which of these actions is taken depends upon the stimulus that is sent to one or the other, and that in turn depends upon the sensory demand for more or less light. The iris also screens the margins of lens and cornea from participation in the lens action required to focus incident or neutralize emergent light.

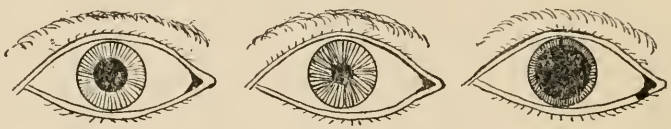
In case incident light is not focused at the retina, but is spread in diffusion circles over it, contraction of the pupil reduces the size and spread of the diffusion circles, and lessens the blur of images. so that, in this respect, its office is that of a diaphragm to

sharpen the definition of images that are blurred by diffusion. The pin-hole disc exemplifies this function, and carries it farther mechanically.

Dilation of Pupil.

The pupil is the gate-way of incident light from objects we see to the retina, and also for special illumination of the retina for the purpose of making an ophthalmoscopic examination of the fundus or eye-ground, and for skiametry or shadow-testing the eye. The latter use of it is confined to those whose practice as optometrists or oculists makes such examinations necessary. In either case the illumination is too brilliant for visual purposes.

But the pupil is also the gate-way for the light that emerges from the eye in an ophthalmoscopic or skiametric examination of the eye. Illumination of the retina for an ophthalmoscopic examination is made both wide and brilliant, so as to make the details of the fundus visible over a considerable field, at least considerably larger than the optic nervehead or disc, and an enlarged pupil is desirable, especially for a wide illumination of the fundus, and advantageous in affording a better view of it. But in a majority of cases optometrists have no trouble to make a sufficient examination of it without artificial dilation.



1 2 3

FIGURE 3.

Dilatation and constriction of pupil by different intensities of light: 1, Normal pupil (4 mm.); 2, constricted pupil, due to intense light; 3, dilated pupil, due to dim light.

In making a shadow-test of the eye, the illumination does not need to be very brilliant, and as but a very small spot on the retina is illuminated, a small pupil, or a normal one, is sufficient. A more conspicuous reflex is obtained by an enlarged pupil, but as this is a test of the refraction of the eye, an enlarged pupil exposes areas of the lens and cornea that the iris shuts out for visual purposes. If it is advantageous to have these areas covered for visual pur-

poses, it is of the same advantage to have them excluded in any test of the refraction. A greater difficulty to shadow-testing is the deep coloring of the fundus by the choroidal pigment.

For refractive purposes, both subjective and objective, the optometrists may regard themselves as having the advantage over those who consider that the pupil needs to be greatly dilated for the purpose of making an objective examination of or through the dioptric media. Objective examination with the ophthalmometer is not of this class, as this is an examination of the front surface of the cornea only, and of its curvature and relative curvature in different meridians, for the detection of corneal astigmatism.

The shadow-test examination is one for the measurement of refraction. As the volume of light required for such examination is little, a large or brilliant light defeats it by stimulating the accomomodation, and to that extent nullifying the findings. It also tends to interfere with a later subjective examination by reducing the reaction of the retina to normal illumination for visual purposes. That is, the visual purple, or chemical agent that sensitizes the rods and cones, is exhausted, or its reaction to light is reduced, affecting acuity of vision.

Motor-Nerve Stimulus.

The motor nerves that supply the sphincter muscles of the iris are said to be tendrils of the third cranial nerves, while those that supply the radials are derived from the sympathetic system. This, as well as the location of the ganglionic center that supplies the stimulus are not matters of any consequence to the optometrist. If the function operates normally and the pupil responds to light, the function and all that goes with it may be presumed to be there.

Nor is it to be considered a static abnormality if the pupils should appear to be unusually large or small, nor even a functional abnormality if they fail to normally respond to light. A patient of this class may have visited someone else before she came to you; or she may be under treatment with some of the powerful alkaloids so generally used in medical practice, for some ailment not connected with the eyes or vision, or with ophthalmic salve, containing atropine or cocaine or both, for infected eye-lids.

The muscles of the iris, or the motor-nerves that stimulate them, are parts of a system that extends to other muscles, exercising corresponding functions. Hence, slight muscular and nervous activity of such other function may produce responsive effects at the iris that its own normal function does not account for. These other possible influences must first be quieted before one can judge the source of them. If the other disturbing factor is functional to the eyes, that may be reached; if not, we cannot reach it.

With pathological causes for an abnormal pupil, or surgical distortion or abnormality, optometry is not qualified to deal, at least correctively. As there are, relatively, very few of them, one only invites trouble to attempt more than lies within his field. Superiority of technique in that field ought to satisfy him.

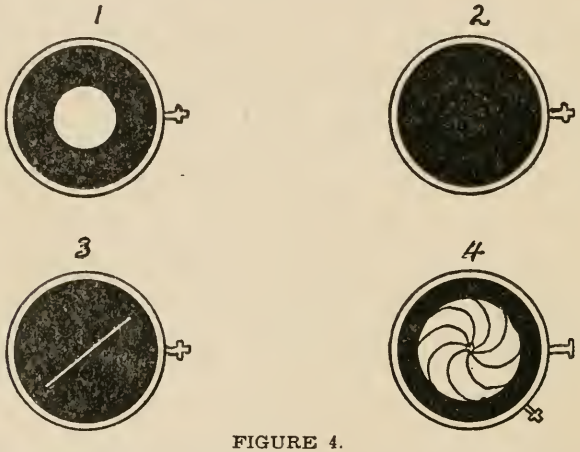


FIGURE 4.

Pupillary Devices: 1, Pupillary disc or diaphragm; 2, pin-hole disc; 3, stenopaic disc or slit; 4, iris diaphragm.

Pupillary Reflex.

Optometry has no special means of controlling the pupil by artificial agents, such as lenses, although the latter slightly increase or decrease the volume of light that is directed into the eye; by their artificial control of other muscular functions of the eye they influence the muscles of the iris, and thereby affect the pupil.

Nature or physiology has provided the eye with the most perfect means of protecting itself from too great a volume or too high brilliancy of light in the reflex control of the pupil. The pupil is the watchdog against irritation that excessive light to the eye produces. It is always on guard to save the eye from any annoyance of this kind. No carelessness or heedlessness on our part, except that of voluntarily going where the light is too bright, will deprive us of this protection, as it is an involuntary action, although nerve-center, motor-nerve stimulation and muscular contraction are necessary to effect it.

But we are not wanting in voluntary means of protecting the eyes from excessive light. We can shut them, or close the opaque lids over them, which is partly a reflex action and partly a voluntary one. We may also turn the head away, or turn our back to the light. We may also hold or wear an opaque screen in such position that it shuts off light from the eye but throws it upon whatever we wish to see. We can also move away from the source of light, and to darker places. But further, we may, if the light is artificial, ah. put it out or turn it down.

These are voluntary acts that we must deliberate upon before we act in order to determine what to do. But before we can consider the question and decide it, the pupil acts involuntarily while we are making up our mind. Such is the nature of a reflex action.

Tinted Lenses.

Although lenses do not directly control the action of the pupil, the eye may be protected from glare and heat by smoked or tinted lenses, which obstruct partially the light that passes through the pupil, but allow sufficient to pass for visual purposes. This tends to tone down the brilliancy of light, so that the irritation caused by a too brilliant light is reduced and the pupillary action is afforded that much relief.

Amber tinted lenses are regarded as affording protection from the irritating effects of the reflection of light from wide areas of snow covered ground, or snow-blindness. The Crookes glass lenses, though designed to shut out certain qualities of light, light of such

high wave-frequency as to have specially irritating sensory effects at the retina, are not designed primarily to lessen the volume of light that is admitted into the eye because of semi-opacity, or opacity of any degree, except to the ultra-violet light.

As to the cause of pupillary constriction, eyes vary greatly in sensitiveness to light. Eyes that are supersensitive to its influence have small pupils, and this quality is termed "photophobia." It is impossible to shadow-test such an eye, or even to make an ophthalmoscopic examination of it. It is exemplified in the nocturnal animals, whose pupils in daylight are very small, but which at night, when prowling for their prey, become large. Such eyes are sometimes found in human beings, though less exaggerated than in animals of this variety.

There is a special science or practice, professing to diagnose disease by the peculiarities of markings of different areas of the iris. But this is not pupillary, nor related to its size.

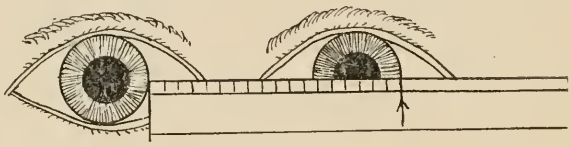


FIGURE 5.
Measurement of pupillary width or distances, inner edge of right to outer edge of left iris, or vice versa.

Magnified Pupil.

The iris and pupil are directly back of the cornea and aqueous humor, both of which are in the positive lens form and therefore have a slight magnifying effect. This effect is increased if the depth of the pupil, or its distance back of the cornea, is greater than normal, as it is supposed to be in myopic eyes. This may account, in part, for an appearance of unusual size in the pupils of myopes, but all pupils are slightly enlarged in appearance by such magnification.

By placing a positive lens before it, this magnification may be increased, and is at its maximum when the lens is at its focal distance from the iris, or from the virtual image of the iris that the corneal and aqueous refraction produces. This means of making a

closer inspection of the anterior capsule of the lens, or of the lens itself, is employed for the discovery of incipient signs of cataract. But it is also used to concentrate a side-light upon the pupil, or of that part of the crystalline lens that protrudes into it, for the same purpose.

Pupillary Discs.

This is an opaque diaphragm, with a central aperture, mounted in a trial lens rim, so as to facilitate placing it before the eye in a trial-frame cell. It is a convenient device to be employed when a surgical operation has left the pupil irregular in form, as it is a central round aperture, and a trifle larger than the normal pupil on account of its position in the cell at some distance from the eye. Oculists, after dilating the pupil, sometimes employ it to confine refraction in shadow-testing the eye to normal visual areas.

The pin-hole disc has a very small aperture in the center. Its use is principally for the purpose of limiting diffusion circles at the retina when the eye does not focalize correctly. If vision is improved by this means, it indicates that there is an optical defect that a lens of the right kind and power will correct even better. It is not to be assumed, however, that if the pin-hole test does not improve vision, there is no such optical defect. The stenopaic disc is a modified form of the pin-hole disc, as it is a pin-hole elongated in one direction. It exposes but one narrow slit to the admission of light, and this may be made to cover any desired meridian of the eye by rotation in the cell.

Pupillary Distance.

This is a binocular term, referring to the straight distance that separates the centers of the two pupils when the visual axes are parallel; or if the eyes are converged to a near object, the shorter distance that separates them, depending upon the distance of the object from the eyes, but usually the reading distance of ⅓ meter, or practically 13 inches. As there is no distinct demarcation of the center of the pupil, corresponding edges of the iris, right or left, are made the basis for measurement. These are referred to as the distance p. d. or the near p. d.

There is a considerable variation between the p. d. of different persons. The average is about 2⅜ inches, or practically 60 mm., counting an inch equal to 25.4 mm. The pupillary distance has nothing to do with the size of the pupil, although it is a very important mechanical factor in fitting frames, or in distancing lenses from each other. It is mentioned here merely because it pertains to the pupil which we are discussing in this section.

CHAPTER III.

Refraction Control.

The static refraction of an eye is its lens-power when in a state of muscular relaxation or rest. Under standard data as to curvature and index, this is estimated to be approximately +58.50 D., which is its refraction in relation to air, and takes into account the effects of the separation of the dioptric surfaces, which are located in the anterior ⅓ of its axial depth. This gives the eye a focal-length of approximately 17 millimeters.

An eye may have greater or less dioptric power than the above and be normal or emmetropic, or have the above power without being emmetropic, for emmetropia is that static refraction, relative to its axial depth, by which light from distant points is focused at the retina, making clear images of distant objects there. Hence, an eye, whatever its refractive power, must have an axial depth to correspond to it to be emmetropic. Its focal-length varies in the same manner.

Dynamic Refraction.

The dynamic refraction of an eye is the lens-power that may be added to its static refraction, and withdrawn from it again, by muscular action. It is effected by increasing the convexity of the crystalline lens only, and principally at its anterior surface. This increase of its convexity is withdrawn again by a reversal of the muscular action that produces it; but is, we believe, due to a muscular action in either direction, which reverses the tension that is applied to the lens for either purpose.

The static refraction of the crystalline lens is about +23.50 D. This is relative to (but not in) air, and takes account of the thickness of the lens, or the separation of its surfaces. It is based on an index of 1.425 for the crystalline lens and of 1.335 for the humors that surround and enclose it. The index factor, relative to air, is therefore, the difference between them, or .09. Hence, to accommodate 1 D, there must be a change of convexity of 1/.09=11 meter curves. For glass of an index of 1.5 in air, a change of 2 meter curves makes 1 D. change in the value of a lens.

The muscular force by which these changes of convexity are made in the crystalline lens is applied directly at some distance from it, and a rather complex system of transmission is required to bring it to bear upon the lens. This mechanism embraces the following:

1. The Ciliary Muscles.
2. The Ciliary Body and Processes.
3. The Suspensory Ligament.
4. The Capsule of the Lens.
5. The Crystalline Lens.

The manner in which muscular force causes the lens to change in convexity is not entirely agreed upon, but there is no question about its being through the above agents.

Ciliary Action.

It is agreed that contraction of the ciliary muscles, one or both sets of fibers, first affects the position or inclination of the ciliary body and its processes. The latter, into which the suspensory ligament is "snubbed," changes the tension on the ligament, and that

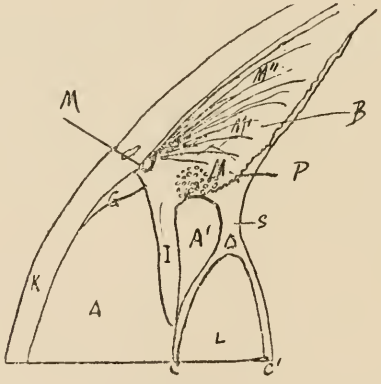


FIGURE 6.
Ciliary Region of Eye: L, crystalline lens; C and C', anterior and posterior lens capsule; S, suspensory ligament; B, ciliary body; P, ciliary processes; M, M' and M'', ciliary muscles; I, iris; K, cornea; G, pectonate ligament.

is communicated or transmitted to the capsule of the lens, either anteriorally or posteriorally or both, for the ligament, at the lens, di-

vides into two sections, one being attached anteriorally and the other posteriorally to the capsule. It is the tension, or release of it, thus transmitted to the lens that gives it greater or less convexity.

Of the two prevailing theories, according to one of them the lens is normally under tension; and action of the ciliary releases it, which allows the lens, of its own elasticity, to convex itself; while relaxation of the muscles causes the tension to be resumed, thus bringing the lens back to normal static convexity; on the other hand, the second theory holds that contraction of the ciliary muscles forces increased convexity into the lens, and their relaxation allows it to subside back to normal form. Neither theory is entirely satisfactory, for either makes the elasticity of the lens the essential factor, either for increasing or reducing the convexity.

According to the first theory also, increased convexity is over the entire anterior surface of the lens; but according to the second a small lenticular bulge is raised on the anterior surface, just back of the pupil, while its peripheral areas are really flattened. The lenticular bulge is accounted for by the resistance of the harder nucleus of the lens to the pressure that is brought to bear upon it, so that high increase of convexity is given to a small area at the exact point where it is required, the pupil. The first is the so-called Helmholtz theory, the second is the Tscherning theory.

The weak point in both theories is that, for either increasing or reducing convexity, the elastic force of the lens substance is a necessary factor. The purpose of muscles is to enable one to overcome the natural forces, and in both directions. Otherwise there is no control, or the control is one-sided. The antagonism of muscles, so generally provided for their exercising functional power by alternate contraction and relaxation in co-operation with each other, according to either of these theories, is wanting; and yet muscular fibers of the ciliary muscles have the antagonistic arrangement. Is that arrangement without a purpose?

The Ciliary Body.

The ciliary body is a triangular ring of pliable tissue, base inward and forward that, at some distance from the crystalline lens,

completely encircles it. The iris is an appendage from its anterior base angle, while the ciliary processes, which grip the outer edges of the suspensory ligament, are a feature of its inner base angle. Contraction of the circular fibers of the ciliary naturally tend to sway or swerve it inward and backward, or to cant or curl it back, rather than draw it toward the lens; while contraction of the radials or fan-like fibers would tend to uncurl it or restore it to its former static position.

Such a backward or inward movement would draw upon the anterior capsule of the lens, and force it into the form Tscherning describes as its actual form of being convexed; while contraction of the radials or fan fibers, would produce pressure upon the posterior capsule, and iron out the special convexity at the front surface, from which the tension would be taken by relaxation of the circular fibers. Instead of being "snubbed" into greater convexity by the release of tension on it, as a ship is snubbed to a wharf against or with the force of the current, or of its own inertia, it is muscularly adjusted to such convexity as is required of it, and by antagonistic muscles, and the alternating tensions they apply to the capsule of the lens, and to the lens within it.

The watery character of the aqueous humor more readily adapts itself to the shape of the anterior surface than the jelly-like consistency of the vitreous humor to any change of shape of the posterior surface, which accounts for the greater response to pressure of the capsule at the anterior surface. It is also more advantageous to have the change of curvature at the anterior surface because it is more effective, on account of being at a greater distance from the retina. Since, to exercise 10 D. of accommodation, 11 times its static curvature of 100 meter-curves is necessary, this high increase would be impossible over the entire anterior surface, but might be easily effected over a small area of it.

Motor-Nerve Control.

It presents some difficulties to explain how the different muscular fibers of the ciliary muscles can be stimulated to these antagonistic actions, since there is no authority for their control by any except

the 3d nerves, and not by different systems as in the iris. But it is possible for the 3d nerves to be so distributed to the fibers as to give them this power. For example, the 3d nerves supply both the superior and inferior recti muscles. But when the eye is turned upward, the superior rectus is contracted and the inferior is relaxed; and the reverse innervation and action takes place when the eye is turned downward.

If it could be found that there is a stimulation of the fan-like fibers of the ciliary muscles along with the stimulation of the radial muscles of the iris, as there is such associataion between the circulars of the ciliary and sphincter muscles of the iris, it would explain the co-ordination of their action. But, as "there are things in heaven and earth not explained by our philosophy," and optometry is more concerned with the optical effects of a muscular action and its motor-nerve stimulation than with the physiological means employed for the purpose, we may pass such questions up to those who specialize in anatomy and physiology, and who have the laboratory facilities for answering them.

So far these higher authorities have not satisfactorily explained the control we have over the convexing of the crystalline lens, and of reducing its convexity, and, as this is but pointing out the weaknesses of existing theories, rather than offering a new one, we can wait for it, especially since the function of accommodation will go on performing its duties just as well as if we knew exactly how they were performed, and to the minutest detail.

Sensory Initiation.

Any function is dormant until some sensory irritation signals it to "get busy." The sensory warning that there is need of greater or less refraction in the dioptric media of the eye is the fact that vision is blurred, and how it is blurred. If it is because of subnormal acuity of vision, or because the media are not normally transparent, we have then no muscular function for improving it. But, if it is because light from the object we are trying to visualize is not duly focused at the retina, then the function of accommodation may be able to rectify it.

The non-focalization of light at the retina causes diffusion circles there instead of point foci, and each of these spread over small areas of the retina, so that the light from different objective points overlap each other, causing confusion in the visual identification of details of the object. A very little diffusion obliterates these details so that only the less detailed general outlines of objects are clearly seen, as all details must be of objects at too great a distance from us.

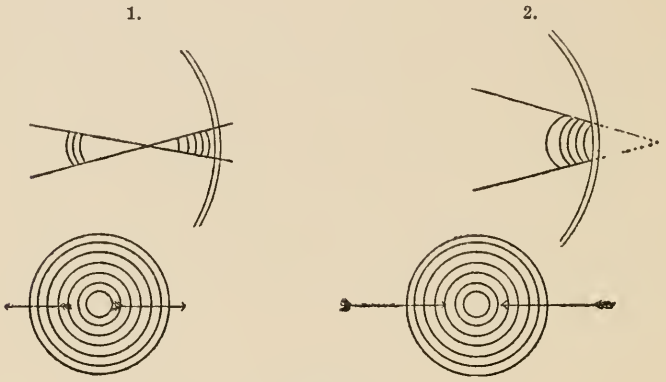


FIGURE 7.

Formation and Development of Diffusion Circles at the Retina: 1, formation and development of positive diffusion circles; 2, formation and development of negative diffusion circles. In lower figures, the arrows point the direction of development of light waves.

Diffusion circles are of two varieties, those due to the interception of the light before it reaches its focus; and second its interception by the retina after it has reached and passed its focus. For the former, the rays are convergent, and the light waves are concave, and the waves therefore fall upon the retina peripherally first and develop inwardly to the axial point; but for the latter, the rays are divergent and the waves are convex, but of much greater curvature than the retina itself, so that they reach the retina at the center first and develop out to the periphery.

The visual sense is able to differentiate these two classes of diffusion circles. The sensation of the first class indicates that greater convexity and refraction is necessary to bring the focus to the retina,

and the motor-nerve stimulus is sent to the circular ciliary fibers, resulting in increasing the convexity of the lens and focalizing light at the retina, instead of back of it. But the other development of diffusion, from a central point outward, indicates that less convexity and refraction is necessary, and the stimulus is sent to the fan-fibers of the ciliary muscles, to reduce convexity of the lens, and so place the focus back upon the retina.

If it is doubted that the visual sense is able to recognize these diametrically opposite forms of diffusion, especially in such intangible impacts as those of waves of light, we have only to refer to what would seem equally impossible, its differentiation of wave-frequency of waves that have a frequency of many billions per second, of which the visual sense takes instant cognizance in seeing colors. The difference between 510,000,000,000,000 and 569,000,000,000,000 waves per second is the difference between seeing an object that is yellow and one that is green in color. What is the purpose of the fine anatomy of the retina if not for tasks such as these?

Motor-Nerve Ganglia.

The function of accommodation is exercised by reflex action, or is an involuntary functional action. There must be a motor-nerve center, or more than one such center, for the purpose, and essentially it may be said to preside over 3d nerve activities. But, whether it is located on the floor of the fourth ventricle just beneath the aqueduct of Sylvius' or at some other spot, and whether it alone exercises this control, or has subordinates farther afield to take charge of an individual muscular action or function, we can only judge by manifestations which is a better basis even than anatomy and physiology for forming a judgment.

The accommodation is called into action by the tendency to diffusion circles, but it only concerns itself with those diffusion circles produced by light from the object we are endeavoring to visualize, and on which the visual sense is centered. For instance, if the object is a page of print at the usual reading distance, and the accommodation has adapted the refraction of the eye to it, it will not focus light that is from objects at a greater or less distance, and these will

form diffusion circles of both varieties, for the nearer objects will focalize back of the retina and the farther ones will focalize in front of it. We visually disregard these, and for them the reflex is inoperative.

But the instant that visual attention is turned from the object at 13″ to one that is farther away, as at 20″, and focused forward of the retina, its diffusion circles become of visual consequence, and the reflex action required takes place instantly, reducing the accommodation the 1 D. needed to eliminate such diffusion. This relieves the muscles that convex the lens of their action, to that extent, but imposes a counteraction upon the muscles that reduce the lens convexity, so that diffusion circles of light from the objects visualized are instantly eliminated, but the object at 13″ is then correspondingly blurred by diffusion circles of the opposite kind. This reflex action is in constant use and activity as we ply our daily vocation.

It would be operated very inadequately if we had to "snub" accommodation up, depending upon the elasticity of the lens only to carry it to the right point; or if we had to snub it back again for an object at a greater distance. An automobile that had to be slanted up hill to provide it with the impetus to back down again; or that had to be directed downward on an incline to get it to go ahead, would not be considered as adequately provided with control. We know that the control of the accommodation works under no such handicap, and therefore that the ciliary muscles are provided with the means of convexing or unconvexing the lens, as required for visual purposes.

Amplitude of Accommodation.

The utmost power, in diopters, that the accommodation can be made to exercise is termed *amplitude* of accommodation. There is a limit to it of course, for the lens, though of plastic material, has its limits in that respect, and the other factors are not infinite. In youth and early life, the lens is most plastic and responds more fully to the tensions that are applied to it. But, as we advance in years, this plasticity gradually wanes, and the amplitude gradually de-

creases. By observation and comparison a table of amplitude has been prepared, and this is the guide to normal accommodation according to age.

At the age of 10 years the amplitude is generally observed to be about 14 D., but at the age of 70 years it is practically nothing. Between these points the reduction takes place at the rate, at first, of about 2 D. in 5 years, but gradually becomes less per year as we grow older. The accepted table is about as follows:

At the age of	
10	14.00 D.
15	12.00 D.
20	10.00 D.
25	8.00 D.
30	6.50 D.
35	5.50 D.
40	4.50 D.
45	3.50 D.
50	2.50 D.
55	1.50 D.
60	1.00 D.
65	.25 D.
70	0.00 D.

But these are approximate figures only, as no one would depend upon them wholly, except as a guide in the determination of the true amplitude.

Accommodation of the above amounts for the different ages is termed normal-for-the-age. But there are other circumstances than age to reduce the amplitude. Among these causes are the non-use of it, for certain static conditions of the eyes make its use of no value for near vision; and certain diseases, such as diphtheria, scarlet fever, grip or influenza so deplete the motor-nerve power that the ciliary muscles are operated but feebly, and the amplitude of accommodation of young people as well as older ones, becomes subnormal for their ages. But this loss of functional power is usually

restored by the recovery of health and physical vigor, although it is sometimes permanently impaired.

Another cause of subnormal amplitude of accommodation for the age is the administration of certain drugs, either internally or externally. If administered internally, this effect is not designed, but is due to the powerful influence of the drug being reflexed to the eyes. But when administered externally, or directly to the eyes, its object is to defunction, at least temporarily, the power of accommodation, so as to enable the examiner to dispose of this bothersome influence while making an examination of the eyes. The drug, in effect, paralyzes the ciliary sphincters, as well as those of the iris, by its deadening effect upon the motor nerves that supply these muscles; but it is, at the same time, stimulating to their antagonists.

Optometrists have reasoned it out, from observation and experience, that the use of these drugs for such purpose, far from being more than a temporary advantage to an unskilled operator, are really menacing, as their effects are apt to be lasting, and that they thus deprive the eyes of the function that is essential to occupational vision. They tend to produce the same impairment of the function as time naturally produces, or to *age the eyes,* setting them forward from an amplitude pertaining to the age of 15 years to that of 18 or 20 years. On school children, whose school work requires the ready adaptation of the eyes to it, the effect is really deplorable, although the lenses that are prescribed in co-operation with their depleted amplitude of accommodation, restores comfortable near vision without impairment of distant vision.

Those employing the drug are deceived into the belief that it is an essential to fitting the eyes for distance; and yet they will find by consulting their own authorities, that the method is not a dependable means of doing this work. The reason for its non-dependability is that a drug of this kind reverses the muscular tension of the ciliary, thus causing the crystalline lens to assume an abnormal flatness of form, and reducing its dioptric value. As a consequence the eye accepts and requires a positive lens of greater power than normally demanded, to take the place of this depletion of its static re-

fraction. This is the real reason for the "deduction" that is made in all positive lens findings by those who use the drug, and for the natural uncertainty of the amount of such deduction.

Demand for Accommodation.

The demand for accommodation with which to increase the refraction of the eye, or to add to its positive lens value by accommodation, rests upon two points or conditions, to-wit:

1. The Static or Structural Refraction of the Eye.
2. The Nearness to it of the Object Visualized.

Assuming the eye to be of normal refraction, or of such optical structure that the exercise of accommodation is not required for seeing distant objects distinctly, then the nearness of the object only is the sole gauge of the demand for accommodative action. When a distant object, or the light from its different points, is focused at the retina without the exercise of any accommodation, then the full amplitude of that power is available for seeing near objects. This condition is termed emmetropia. In emmetropia, the demand for accommodation is said to be normal-for-the-distance of the object, or merely normal-for-the-distance. This is quite different than what is termed normal-for-the-age.

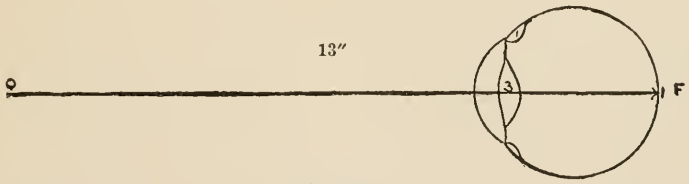


FIGURE 8.

Emmetropic eye, with 4D. amplitude of accommodation, fixing object at reading distance, 13″. O, object at 13″; 3 in crystalline lens, accommodation in force; 1 in ciliary body, accommodation in reserve; F, focus of light from O at retina.

The nearness of an object, or rather the distance of a near object, is measured in meters, so that it may be readily reduced to metric curvature or diopters by taking its reciprocal. A meter is equal to about 40 inches, or 39.37 inches. Assuming it to be 40 inches, each inch is 1/40 of 39.37 = .984 of an inch. If we call

this value 1 metric-inch, we may express short distances in them, using the sign (″) to represent them. Then we are saved from the trouble of making the reservations "nearly" or "almost" when giving distances in them. On this basis, although the real inch has 25.4 millimeters in it, 25 mm. = 1″. It will be assumed, when the above sign is used, that metric-inches are referred to, so that 16″ or 20″ means that number of metric-inches.

Accommodation that is normal-for-the-distance is equal to the metric curvature of incident waves of light from the object to the eye, or to the *correction-plane* of the eye, where a lens would be placed to neutralize it. Such incident metric curvature of the waves for the ordinary distances is as follows:

Infinity = 6 meters, 20 ft. or more,	waves 0, acc. 0.
1 meter = 40″	waves+1, acc. 1.00 D.
½ meter = 20″	waves+2, acc. 2.00 D.
⅓ meter = practically 13″	waves+3, acc. 3.00 D.
¼ meter = 10″	waves+4, acc. 4.00 D.
1/5 meter = 8″	waves+5, acc. 5.00 D.

With the above accommodation, for the respective distances of the object, an emmetropic eye will focus it at the retina, and a clear image of the object visualized will be formed upon it.

Sustained Accommodation

In visually fixing an object at any near distance, the emmetropic eye must accommodate normal-for-the-distance. But, when the object is a page of reading matter he is perusing, that accommodation must be *sustained,* for the moment it is relaxed or over-exercised the print, if not moved to a corresponding distance, becomes indistrict. As the amplitude of accommodation, given on a preceding page, is the utmost power that it can exercise, it follows that this power cannot be sustained, but is only a momentary exercise of it. Hence, for sustained reading at any fixed near distance, the whole amplitude cannot be employed, but only such part of it as can be maintained for a considerable period of time, leaving the balance in reserve for special use, if needed.

Some differences of opinion are found as to the proportion of

the used to the reserved accommodation for ordinary near vision or reading. It is the opinion of the writer that, as a standard, but about half of the amplitude should be so engaged, although this may be crowded a little when the need of artificial assistance first becomes manifest, by moving the printed matter a little farther from the eyes. This division divides the amplitude 50/50 between the used and the reserved portions of it. Then, by relaxation, more distant points may be fixed; while the employment of a little of the reserve will enable one to see objects at a nearer distance, as in referring to finer printed matter, such as may be found in foot-notes or tables. This we call the *range* of vision or of accommodation, the former being expressed in distances, the latter in diopters, but are reciprocally equivalent to each other. By comparing these equivalents in the above list of values, it will be seen that the shorter the distances the greater the dioptric value of their differences of distance, or the less the distance required for 1 D.

Presbyopia

When age has so reduced the amplitude of accommodation that, notwithstanding the fact that all of it is available for near vision, none being required for distance, it is insufficient for sustained near vision without discomfort, and requires lens assistance, the condition is called presbyopia. This is a deficiency of the function of accommodation due to age and the hardening of the lens, and is not a muscular deficiency. Muscular weakness, due to illness, is not presbyopia, although optically considered, it may require, temporarily, the same means of relief. Taking, for example, an emmetropic eye having the amplitude of accommodation of 4 D. For sustained reading at 13″ it would require to accommodate 3 D., or use ¾ of its amplitude continuously.

That would soon cause eye-weariness, and to relieve it the paper being read might be moved farther away. But if the print should be rather fine, the retinal images would be quite small and difficult to see distinctly. A more brilliant light might help matters temporarily, but that is not the real trouble. But the eyes with an amplitude of 4 D. can use 2 D. comfortably and continuously. Hence, if both eyes are in the same condition, and a pair of +1 D. lenses are properly

mounted before them, accommodation for 13″ will be reduced to that amount, and a reserve of 2 D. of amplitude will be provided for them. These lenses will of course blur distant vision, but as little as necessary, and provide comfortable and sustainable vision at reading distance, both for coarse and fine printed matter.

With the above lenses, placed at the correction plane, which is at a distance of 14 mm. from the eye, the farthest point of clear vision is at the anterior principal focus of the lens, 40″ in front of it. But, as there is no accommodation required for that distance, the 4 D. of amplitude can be added to it, making 5 D. in all, so that the nearest point of distinct vision becomes 8″ instead of 10″. The lenses therefore provide the following range of vision:

Farthest distinct vision.....40″ acc. 0.00 D.
Nearest distinct vision..... 8″ acc. 4.00 D.
Comfortable and sustained near vision..13″ acc. 2.00 D.

Stronger lenses would lessen the accommodation required for reading, but they would blur distant vision more, and the function of accommodation by having insufficient exercise, would deteriorate more rapidly.

As all eyes, whether emmetropic or not, are assumed to be first examined and corrected for distant vision, they are also assumed to be made, by such correction, artificially emmetropic, the above principles for correcting presbyopia with lenses apply to all eyes. But it is not therefore to be thought that all eyes follow the above principles with exactly the same additions or presbyopic lenses. It is better to defer the correction of this functional weakness until necessity compels it to be made, for the eye can accommodate no more and no less with these lenses than without them, and the preservation of the power by exercise of it is to be taken into account. But also, people are of different physical dimensions, some with long arms and some with shorter ones; and occupations or avocations are different, so that some require specially near vision and others more distant near vision. But the essential common principle is this: Comfortable and sustained vision at the "working" distance, with the ampli-

tude of accommodation so divided that, for greater or less distances, it is equally apportioned in diopters, though not in distances.

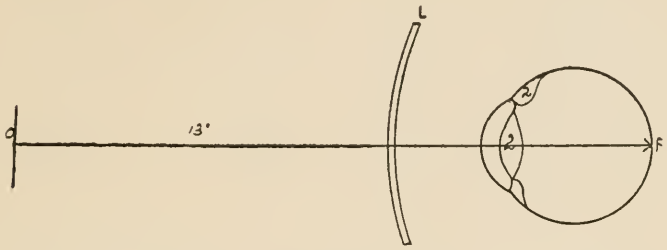


FIGURE 9.

Emmetropic eye viewing object at 13" through a +1 D. spherical lens. O, object, page or printed matter; L, +1 sph. before the eye; figure '2' in lens, accommodation exercised; figure '2' in ciliary body, accommodation in reserve; F, focus at retina.

Neurometry of Accommodation

While the function of accommodation is exercised directly by ciliary muscles, the burden of it falls finally upon the motor-nerves that enforce the action of the muscles. We measure the accommodation in diopters, or physical units, in which 2 D. is exactly double 1 D., and all are in the ratio of their numerical expressions. But this is quite different than the supply of motor-nerve force or energy with which to exercise these optical effects. Like the climbing of a series of stairways of exactly equal dimensions throughout, they grow more difficult the farther we ascend them. If we apply the common law of increase to this expenditure of nerve force, as exemplified in the law of friction and similar things, we will find the ratios to be as follows:

Assume the unit to be that nervous expenditure required to exert the first 1 D. of accommodation, or to flex the lens the 11c required amount. This is, from the motor-nerve standpoint, the easiest diopter of all. It varies with age, health, etc., and for different persons having age and health equality; but it is not intended to apply it to different people. Let us represent this expenditure of motor-nerve force by the unit, 1*n*. We may call it one neuron, or what we choose. Then, as this force has to be continued while we are nego-

tiating the second, increased accommodation, for emmetropic eyes, is as follows:

Distance:	Accom.	Nerve-force	Increase
Infinity	0 D.	0 *n*	0 *n*
40″	1 D.	1 *n*	1 *n*
20″	2 D.	4 *n*	3 *n*
13″	3 D.	9 *n*	5 *n*
10″	4 D.	16 *n*	7 *n*
8″	5 D.	25 *n*	9 *n*

To those who would question this, or any similar principle or law of increase, it is suggested that they consider the fact that the exercise of increasing power of accommodation is not merely the question of taking on more load, but that, in negotiating each subsequent diopter, that which has been previously assumed has to be held. One brick weighs approximately the same as another of the same kind; but when one has to hold the two he has already picked up while picking up the third, and the three while he is picking up the fourth, these have to be carried down and up in the excursion for the latter, so that, for the 3d, two go down and come back with the elevation of the 3d, making $4 + 1 = 5$ of the single trips; and for the 4th, it is 2 3's = 6, and 1 more, making 7 in all. The diopters of accommodation exercised are not fastened to place as we reach for an additional one.

But the strongest indication that this or a similar rule prevails is the fact that, when we supply the patient, who is verging on presbyopia, with a weak plus lens, he gets excessive relief from it in proportion to its dioptric value. The reason for this is that the lens relieves the accommodation of taking on and carrying the higher and harder diopters, and leaves the function to negotiate the easier ones only. Hence, in the case of the presbyope who is given a +1 lens above, reducing his accommodations for 13″ from 3 D. to 2 D., we cut the motor-nerve force required down from 9*n* to 4*n*, or take off 5*n* from the normal demand for motor-nerve force for 13″ vision. This is an abatement of over ½ of that force he would otherwise be compelled to use for seeing at the reading distance, which is an abatement indeed. We do not double this for the two eyes, for the two act together more easily than one alone.

The Time Element

To appreciate the motor-nerve expense involved in accommodation in the higher diopters, for reading, one must not neglect to take the time factor into account. A momentary use of a high degree of motor-nerve energy would be of little consequence, but when this is continued, time becomes an important factor. Reckoning time in seconds, not to say in "split" seconds, as required in the exposures for moving picture photographs, there are 60 of these in a minute, and 3600 of them in an hour. When we are reading an interesting book, hour after hour may be passed away with scarcely a let up in the accommodation.

In the presbyopic case we have referred to, an emmetrope with an amplitude of accommodation of 4 D., who needs a +1 lens to relieve it of excessive accommodation, or the eye-wearying work involved in reading at 13", we may compare its expenditure with and without the assistance of the lens. The results of this comparison are as follows:

For 13" vision	Accommodation,	Motor-nerve force
1. Without the lens,	3.00 D.	9 *n*
2. With the lens,	2.00 D.	4 *n*
Excess per sec.	1.00 D.	5 *n*
For 1 minute,		
1. Without the lens,		640 *n*
2. With lens,		240 *n*
Excess per minute		300 *n*
For 1 hour,		
1. Without lens,		32,400 *n*
2. With lens,		14,400 *n*
Excess per hour,		18,000 *n*

As a matter of fact, no presbyopic reader of this amount would be able to stand the strain of such a wasted expenditure of force. He would be compelled, at short intervals, to "rest up" the accommoda-

tion, which an emmetrope can do by merely visualizing a distant object, like an advertisement on a bill board across the street; or at night, at something across the room; or subconsciously he would hold his book a little farther away, getting relief for every inch of increase in the distance, but correspondingly reducing his angle of vision.

CHAPTER IV

Abnormal Structures

If all eyes were of normal optical structure, emmetropia, there would be little for the optometrist to do. His practice would be confined to the fitting of presbyopia and spectacle and eye-glass frames, which latter is an art in itself. But, as there are many eyes whose optical structure is abnormal in some particular, the practice of optometry is greatly extended; for distant vision is impaired or the muscular functions are disturbed or disarranged, and lenses correct these abnormalities or defects.

These defects of optical structures are usually referred to as "errors of refraction"; but why should an eye whose lens system is of a perfectly spherical form and action be so designated? If such action of the dioptric system of the eye is adapted to its axial depth, the eye is emmetropic; but if it is not so adapted to its axial depth, it is ametropia. Hence, neither the refraction, if spherical, nor the axial depth of the eye, by itself, can be regarded as the defective factor. It is the *relativity* of the two to each other that makes the eye either emmetropic or ametropic.

With this obvious fact in view, we may define the different optical structures of the eye as follows:

1. *Emmetropia,* an eye whose refraction and axial depth are in normal relationship, or agree with each other.
2. *Ametropia,* an eye whose refraction and axial depth are not in normal relationship, or agreement with each other.

These are structural definitions, as nothing is said about the functional effects of either the agreement or disagreement between the two factors; and we are chiefly concerned with these functional effects. To define them functionally we must first differentiate between the classes of structural defects. There are but two of them: *myopia* and *hyperopia.*

1. In *Myopia* the refraction is excessive for the eye's axial depth; or its axial depth is excessive for its refraction.

2. In *Hyperopia* the refraction is deficient for the eye's axial depth; or its axial depth is deficient for its refraction.

This apparently inverted relationship is due to the fact that the greater the refraction of the eye the less must be its axial depth to make the two agree; so that a strong refraction and a short eye are adapted to each other, while a weak refraction requires a long eye. An eye of any positive refraction will be emmetropic if its axial depth corresponds to that refraction.

We sometimes hear the optical defects of the eye explained on the basis of their *over* or *under* development. This view of the case fails to consider that, if an eye is under-developed and small, the metric curvature of its dioptric surfaces is correspondingly increased, which correspondingly increases its refraction, as the index of the media is not assumed to be disturbed; and the dioptric surfaces are probably nearer to each other, which reduces the deduction resulting from their separation. A bird's eye, in spite of its smallness, may be emmetropic or ametropic. It is not made hyperopic by its smallness; nor is an ox's eye, because of its largeness or length, made myopic. Smallness increases the curvature, largeness reduces it, so that refraction is correspondingly, or rather reciprocally, affected.

Functional Effects

The most important light in which to regard abnormalities of optical structure in the eyes is in their functional effects or consequences, for they disturb and disarrange the muscular function of accommodation. As a consequence, some eyes have near vision without accommodation, or less than the normal amount for the distance of the object; while others require to accommodate for distance, and more than normal for all near distances. In a state of accommodative rest, an ametropic eye will have either blurred distant vision, with good near vision; or blurred vision for both far and near, especially for near vision.

Accommodatively considered, the different states of optical structure result as follows:

1. *Emmetropia* causes accommodation that is normal for the distance of the object.
2. *Myopia* lessens the demand for positive accommodation at all distances, but impairs distant vision.
3. *Hyperopia* increases the demand for accommodation for all distances, and requires it for infinity.

As a consequence of this disarrangement of the exercise of the function, the under-use of it, like that of any muscle, leads to torpidity, or to dispossessing it of the power to act normally, if called upon to do so. On the other hand, the over-use of a muscle, especially for continued periods, tends to develop an inability of the muscle to relax, or to relieve itself of its burden; or to fluctuate in action so that it becomes difficult to reduce it to a state of rest or quiet. These eccentricities are sometimes hard to subdue. However, since the effects are as opposite as the structures, we must consider them separately or individually.

Myopia

Myopia deprives the eye of clear distant vision, for the light it receives from distant points is focused before it reaches the retina, and passing on from this point, spreads out and forms a diffusion circle at the retina. It is of the kind that causes the wave impacts upon it to develop from a central point outward to the periphery of the diffusion circle, which warns the visual sense of its character. As every objective point in the distant object is similarly represented at the retina, the diffusion circles overlap one another, and the image lacks sharpness of definition. This is a matter of such a nature that a high degree of visual acuity, instead of helping it, makes it all the more apparent. We visualize these images, rather than the objects; the visual sense has nothing else to go by.

It may be asked why such bad focalization is not neutralized by that action of the ciliary muscles that flattens the lens and reduces its refraction to such an extent as place the foci at the retina, thereby clearing distant vision. The answer to this question is, it is quite a different matter to flatten the lens below its normal convexity than to increase that convexity. The normal use of the radial ciliary

fibers is to take a specially acquired convexity out of the lens, to reduce it, after positive accommodation, back to its normal static form, as when you straighten a strap by pulling at its opposite ends. That part of it is easy. But when it is straight, you may, by exercising unusual tension, get it to yield a little more to its length. This may also be done to the lens. Statically, or when at rest, it is *balanced* by the pressure of the opposite humors upon it. It is easily con-

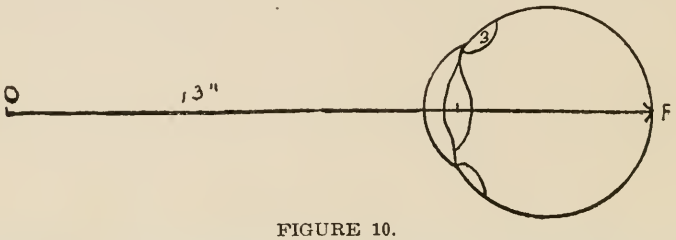


FIGURE 10.

Myopia of 2 D. with amplitude of accommodation of 4 D., viewing a reading card at 13". 1, accommodation exercised for object; 3, accommodation unused or in reserve; F, focus at the retina, vision normal for the distance.

vexed, and restored to normal form, when it is watery and plastic, as in youth. But to reduce its convexity below that point can only be done in extreme youth, and for but a slight value, as about a single diopter at 12, and not more than 1.50 D. at 10 years. After the age of 12 it may be left out of consideration, except as a neutralizer of accommodative convexity.

Inductive Effects

The neuro-motor control of muscles corresponds more nearly to electric control than any other force, and corresponding terms are used and will be understood. The inductive influence of ciliary action on other muscular functions is manifest chiefly at the iris, and upon the extrinsic muscles. As myopia gives the greatest occasion for the functional action of the radial fibers of the ciliary muscles, the inductive influence of this action, at the iris, is to stimulate its radial muscles by such influence. As a consequence, myopia and a dilated pupil, or at least a large pupil, is a matter of common observation. We will not speak of the opposite influence at this time. It may be that part of its enlargement is only apparent, and is due to magnification, but there is an actual enlargement.

This cannot be accounted for on the ground that the myopic eye demands a greater volume of light, and therefore its pupil is expanded. Myopia derives its name from the fact that there is a tendency to close the lids, and shut out light, and for the purpose no doubt of lessening the area of the circles of diffusion and improving the definition of images. But the inductive influence of the action of the radial fibers of the ciliary over those of the iris is a stronger influence, and in opposition to it. There is also an influence of the same general character on the external recti muscles, giving the myopic eyes, usually, an outward cast, or exophoria. How the radial muscles of the iris, the fanlike fibrils of the ciliary muscles, and the external recti muscles are nervously connected is a question for the anatomists; but it may be remembered that *induction* does not require contact, or actual nerve connection. This association however tends to confirm the double functioning of the ciliary muscles.

Auxiliary Effects

The special activity of the fan-fibers of the ciliary muscles in myopia is confirmed by a number of further facts of a corroborative character. One of these is the noticeable development of these fibers, in comparison with the circulars, in the post mortem examination of the eyes of a myope. In emmetropia, and especially in hyperopia, these muscles are thin and tendonous, while the circulars have the opposite character. But this evidence of little use in emmetropes and hyeropes does not materialize in myopes, although the circulars are always considerably more developed, as they are the more essential or more direct agents of accommodative activity, and the fan-fibers function principally as checks to them.

As these ciliary fibers extend toward or to the apex of the triangular shaped ciliary body, if not into the choroidal tissue back of it, their contraction has a stretching effect upon the choroid, and tends to draw it away from its normal attachment at the optic nerve-head, or disc, which accounts for the white ring or crescent that surrounds, partly or wholly, the optic disc, which is a characteristic of myopia. It may thin out or cause slight posterior staphyloma, accounting also for increasing or "progressive" myopia, if the defect is

not corrected early and in full, or as nearly full as possible for comfortable wearing at the time the correction is made.

Myopic asthenopia is another indication. While for myopia of a degree that cannot be so neutralized for distance, even by a young person, it will only be employed to read at a distance slightly beyond the static far point, for within the far point distance the positive accommodation is employed, and asthenopia is unlikely, except in case of astigmatism. But a low degree of myopia in quite young people, which offers results from this ciliary action, the strain of it may be such as to make distant, or even near vision, painful and uncomfortable, indicating that, although the functional action takes place, it is not one to be enjoyed. A weak plus lens, in such cases, relieves the asthenopia, but impairs distant vision much in excess of its dioptric value. It is explained by the fact that it so increases the myopia as to take it beyond the range of this functional action.

The other important corroborative fact we have already referred to, to-wit: the myotic effect of a drug used to pacify or paralyze ciliary action. The drug undoubtedly has that effect upon the circular fibers of the ciliary, but it is not needed in myopia. Its effects upon other ciliary fibers, corresponding to its effects upon the radial muscles of the iris, is to stimulate them to activity, or to force them to so act as to flatten the lens, even below normal static form. This action is effective in reducing the apparent myopia, but only for a small part of its static refraction—not enough to warrant the use of such heroic measures. If the myopia is slight, the eye might be made to appear emmetropic, or actually turned into hyperopia by it. However, these strenuous effects are no longer sought by the drug users, and a milder distillation of a less powerful cycloplegic is considered to answer the purpose, which is mainly psychological.

Far and Near Points

The limit of a myope's distant vision is the reciprocal, in meters of the myopia. This is obtained by dividing 100 by the myopia for the distance in centimeters, or 40 by the same for the distance in metric-inches. As it is forward of the eye, it is termed a

plus distance. For 4 D. of myopia this far point is at a distance of 100/4 = 25 cm.; or 40/4 = 10″. No accommodation is required, and none may be exercised, for the focalization of light from that distance. Therefore, the full amplitude of the accommodation is available for the focusing of light from a nearer point. If the amplitude of accommodation for the 4 D. myope is 6 D., the near point is found by taking the reciprocal of the sum of the two, myopia and amplitude, or 4 + 6 = 10, the reciprocal of which is 10 cm. or 4″. The range of vision is then from 4″ to 10″, or from 10 cm. to 25 cm., or vice versa.

The range of vision has to be stated by giving the two extremes of distance, near and far, of distinct vision. It cannot be stated by giving the distance between the two. In the above myopic case of 4 D., with an amplitude of 6 D., the space from the near point to the far point is but 10 — 4 = 6″. But we would be very indefinite if we merely stated it to be six inches. If the near point of an eye is 10″ and the far point is 16″, this also is a difference of 6″, but how different the two eyes are in range of vision and in amplitude and optical condition. The latter eye is 2½ D. myopic, and has an amplitude of accommodation of 1½ D. That is, the far point at 16″ shows 2½ D. of myopia, and since the near point is at 10″, representing 4 D. of normal accommodation, the real amplitude is 4 D. — 2½ D. = 1½ D. We must know *where* the six inches is located to determine what the amplitude and refraction are, the abstract distance between the far and near points tells us nothing.

The far point is termed the *punctum remotum,* or p. r., and the near point is termed the *punctum proximum,* or p. p. The *punctum comfortable,* or p. c. is usually placed in a particular position by the lenses that we prescribe, for without the lenses we are not apt to have any. For example, in the case of the 4 D. myope, with 6 D. accommodation, he may be able to read comfortably at his far point, but can see distinctly there only with a fully relaxed accommodation. For nearer distances only, he draws upon it. This is too near, for although the accommodation is relaxed, he must converge the two eyes to that distance to have binocular single vision of it, and that may be an effort, besides introducing other complications that cannot be discussed here.

But, as we are not considering the procedure in fitting the eye or eyes with lenses, but merely their optical conditions and functions, it would be outside our purpose to extend the discussion any farther than necessary for the purpose.

Presbyopia

The myope becomes a presbyope in due course of time, probably at an earlier age than an emmetrope or hyperope, on account of the function of accommodation being undeveloped by non-use, unless he is corrected. His myopia, as if it should be 2 D., would postpone the time when reading lenses would be necessary to the neighborhood of 55 years, or to the age when an emmetrope requires +2 lenses for his presbyopia. When the emmetrope begins to wear +2 lenses for reading, he converts himself into a 2 D. myope with the lenses, or makes the eyes artificially of that optical condition. He is blurred 2 D. for distant vision the same as a 2 D. myope, and he can read at 13″ with 1 D. of accommodation the same as the myope.

But, should the 2 D. myope be corrected for distance in early life, so that the accommodative function would be developed normally, his near vision would fail at about the same time as that of a natural emmetrope. Presbyopia is *corrected* by myopia, not eliminated by it. A myope of an amount exceeding 3 D. must wear minus lenses for comfortable and normal vision at 13″, for his far point is nearer to the eye than this. A 6 D. myope, in order to see at 13″ must wear at least —3 lenses. If his lenses are —6, to correct his myopia, he must accommodate normally for the distance, as these lenses make him artificially emmetropic. If —5 lenses are the appropriate ones for such reading distance, these may be considered to represent the —6 lenses, with +1 added for presbyopia. Nobody can escape presbyopia with his life.

In myopia as in emmetropia, the due correction of presbyopia must require a plus lens, in as much as it replaces statically a plus functional power. But what the amount of the presbyopia is, is relative to the static or structural refraction of the eye. Two men may wear, each —2 lenses for reading at 13″. That does not indicate that their eyes are alike. One may be a myope of 3 D. but with I D. of presbyopia; the other a 4 D. myope, but with 2 D. of presbyopia.

If their mountings fitted each, either might wear the other's glasses for reading; but if they were converted into bifocals, neither's would do for the other. And a lost or detached scale from a lens of one pair, would not answer for either lens of the other pair. Besides, if the distance corrections and the additions were the same, the scales of one might not fit the others on account of being ground on different curves.

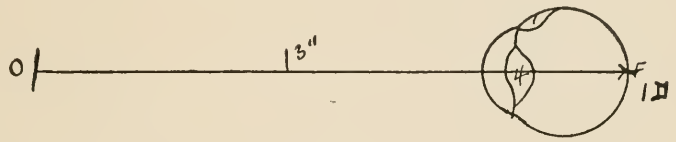


FIGURE 11.

Hyperope of 2 D. with amplitude of accommodation of 5 D., endeavoring to read at 13". O, object; 4, accommodation exercised (not sufficient); 1, accommodation in reserve (exhausted); F, focus 1 D. back of retina, blurred vision.

Hyperopia

Hyperopia of a limited amount does not impair distant vision, when the accommodation is of sufficient amplitude to neutralize it for that purpose. The eye focuses the light from distant points by exercising accommodation equal to its hyperopia. It must maintain this amount continuously to see distant objects clearly, however. Hence, with age, and the consequent loss of accommodative power, the time comes when even vision of distant objects is impaired by it. It is this possession of distant vision by the hyperopic eye that led to its being named "far sighted" from which the term "hyperopia" is also derived. The age at which distant vision is impaired depends upon the amount of hyperopia.

With a rather low degree of hyperopia, near vision may be maintained for a number of years, as well as distant vision. But, since near vision requires more accommodation than distant vision, near vision is impaired long before there is any apparent impairment of distant vision; and it is this maintenance of distant vision, after near vision has long been impaired that causes it to be referred to as above or by the corresponding term, "long sighted". When the near vision of a person begins to be impaired at a rather early

age for presbyopia, but distant vision remains normal, it is pretty surely because the person has hyperopia of a greater or less amount. The age at which presbyopia really begins in normal eyes is at about the age of 38 years, although glasses are not usually prescribed for it until the age of 43 or 45.

Let us consider the case of a person of 35 years of age, with but 1 D. of hyperopia, the eyes being otherwise normal. At that age there is an amplitude of about 5.50 to 6 D. of accommodation. This hyperope must accommodate 1 D. for distant vision, using this easiest of all diopters of his accommodation for it. For reading at 13″ he must employ 3 D. more, or 4 D. in all, to see the type clearly. This is considerably over half of his amplitude, and the eyes will weary under its continuous use. But, as is universal with hyperopes, he will stoutly maintain that his eyes are "just as good as ever". Why shouldn't he? He can see perfectly, both near and far. Glasses, why does he need glasses? That is the layman's point of view, and is held universally, even by some college professors. Glasses are for those who need them, not for such as he.

Further Examination

Perhaps the above patient suffers some lapse of health, perhaps he has an unusual amount of near work to do, or perhaps some dimness that he observes in his vision, after a long period of night reading with an unsatisfactory light (lights become unsatisfactory to him at about this time). An examination shows the 1 D. of hyperopia manifest. He just desires the glasses to help him along with some special work, and gets the prescription filled. They fill his requirements exactly and he goes at his job with them on, taking them off as soon as he is through, as there is "no further need" for them. There are probably many thousands of people, counting in the university professors, the doctors and the lawyers, the school teachers, the nurses and the thousands of others at this age that this description fits.

But by mere accident or experimentally, the wearer neglects to take them off when he or she stops near work. They may slightly blur distant vision at first, but they feel comfortable, and soon they become a most desirable "easement" to their eyes. Both distant and

near vision is now perfect and comfortable. In fact it is rather disagreeable to be without them. Our Mr. Brown or Miss Jones has become a perennial spectacle wearer, and why? Oh, the "habit" has been formed; the glasses have made themselves essential, and the "doctor" who fitted them is responsible for the consequences, for before they were worn there was no need of them; and that is the layman's view again.

But, there is another view of the situation, a "prejudiced" one of course, that the 1 D. hyperope cannot get a pair of +1 D. lenses, in any form of mounting, before his eyes too soon. That 1 D. of hyperopia, uncorrected by lenses, makes 1 D. of accommodation necessary all of the time, and adds 1 D. to the accommodation required for near vision at any distance. To the 3 D. normally demanded for ordinary reading, this added diopter is the 4th. For any distance of the object, there is never a complete relaxation. It is quite easy for one who is young and healthy to maintain 1 D. of accommodation, especially the easiest one in whatever series of diopters of power the eyes have. But, spending that power on distant vision, wasting it, leaves the harder ones for necessary use in near vision; and in motor-nerve force, the price gets higher all the way up, and is greatest at the 4th if one goes no higher.

A glance at the "neurometry" of it will be helpful, that is, will help to impart an understanding of it. The neurometry involved in 1 D. of hyperopia may be displayed as follows:

Object distance	Accommodation	Motor-nerve Force
Infinity	1 D.	1 *n.*
40″	2 D.	4 *n.*
20″	3 D.	9 *n.*
13″	4 D.	16 *n.*
10″	5 D.	25 *n.*

The reason for including distances nearer than the normal 13″ reading distance is that anyone, reading at that distance, will occasionally be required to scrutinize a poorly printed word or the finer type of any foot note at a nearer distance, so that a distance of 10″ is frequently necessary to make the print clear. But, for vision at

13″ the motor-nerve force required is 16*n*, and this is 16 — 9 = 7*n* more than normal, or the amount required of emmetropia for the same distance.

Whatever may be said of it, or the necessity of wearing lenses to correct 1 D. of hyperopia, it is obvious that the want of such correction causes the expenditure (waste) of a rather large amount of nervous energy, as it is this motor-nerve energy that operates the ciliary muscles by which the required accommodation is effected. And the store of motor-nerve energy in the body, or its generation for motor purposes, is not confined to this purpose. It serves all demands of the organs of the body, heart, lungs, liver, kidneys, stomach, intestines, and even the exercise of the mental faculties. A pair of eyes of this kind, therefore, represent a serious *leakage* of nervous energy, motor-nerve force. One cannot say what consequences are most likely to follow. Perhaps it will be nothing perceptible, but that is not likely. At least, sooner or later, it will manifest itself at the eyes in impaired vision.

Finding Hyperopia

With perfect distant and near vision, hyperopia is concealed from direct observation. Myopia is open; no one can hide it; it impairs distant vision. But hyperopia, which is covered by ciliary action or accommodation, must be searched out. We cannot look into the eye and see it, although by impairing vision of the fundus in ophthalmoscopy, it may indicate its presence to an expert observer. A distant vision test will not disclose it; nor will a near vision test, unless the person's age is taken into consideration, or accounts for the failure of near vision. Even then we only guess what part of the impairment is due to hyperopia, and assign the rest to presbyopia; or we had better guess, if we guess at all, what part of it is presbyopia, and assign the rest to hyperopia, as the age alone will afford us a key to guessing the presbyopia with a greater degree of assurance than we can guess the hyperopia.

But these would not be *findings,* as there is nothing certain within our grasp. We must test the eyes, either subjectively or objec-

tively, to ascertain the facts. Subjectively this is done by ascertaining what weakest plus lens blurs distant vision, or what strongest plus lens has no such effect. The objective method is to shadow test the eye, which is the most complete objective method of measuring its optical condition, measuring its refraction, (relative to its axial depth) as required. Without going into the details of either of these methods, we consider the case from the visual standpoint, as that is the final arbiter of the facts we can depend upon, although it may take us some time to get at the *bottom facts* even by this method, but the superficial ones are easy.

Subjective Findings

If an eye is hyperopic, for a person not so far along in life that the accommodation has become inoperative, and also if the hyperopia is not too great to be neutralized for distant vision, the eye will exercise the necessary accommodation to see distant objects distinctly. As the action is involuntary, the accommodative instrumentalities, sensory and motor, act for themselves without consulting us about it. When the sensory requirement exists the motor response takes place. Therefore, to put a stop to it at the "fountain head" the sensory initiative must be eliminated, and a plus spherical lens before the eye is the agent we employ. If the eye is 1 D. hyperopic, or if it accommodates 1 D. while viewing distance, a + 1 sph. before the eye makes that action no longer necessary, and the accommodation is relaxed.

The accommodation is thus forced to relax by the same method that, without the lens, it is forced to act. If it continued to act after the lens was placed before it, it would focus light from distance forward of the retina, and the sensory warning of this causes the nerve center to withdraw stimulation from the contracting muscle and send it to the opposing muscles. Both are therefore reflex actions and involuntary. Unless distant vision is impaired by the lens, we know that accommodation has been relaxed. To be sure as to the quantity, we place a plus lens of sufficient dioptric value before the eye to impair distant vision, or *fog* distant vision with a plus lens. Then, by reductions we obtain the strongest plus lens that will not impair

distant vision, and this lens measures the amount of the accommodation that is relaxed or abated, and therefore the *manifest* hyperopia.

The above method of procuring accommodative relaxation, while the vision is fixed upon distance, and thus determining the amount of hyperopia, is the initial work of what is known as the *fogging* system of suspending the accommodation. Unless the eye is accommodating for distance it cannot be relaxed with a plus lens. If it is hyperopic and does not accommodate for distance, distant vision will be blurred without the lens but the lens will improve it. Therefore this way of uncovering accommodative action, and of neutralizing it or replacing it by a lens, for the purpose of making the hyeropia apparent, and measuring the amount of it, is the principal subjective staff upon which optometry depends to determine optical defects of the eyes that are hyperopic. Myopic eyes are fogged by their myopia.

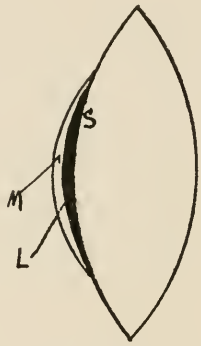


FIGURE 12.

Ciliary eccentricities. S, static form of lens; L, latent or unrelaxable convexity of lens; M, manifest or relaxable convexity of lens.

Ciliary Eccentricities

It would seem, without astigmatism, that the correction of eyes with lenses were a very simple matter. Myopia is corrected by the weakest minus sphere that gives the best vision; hyperopia by the strongest plus sphere that does not impair distant vision; presbyopia by the weakest plus addition to the distance correction that pro-

vides a suitable range of vision in opposite directions from the p. c., 2/3 toward the p. r. and 1/3 toward the p. p., and half of the amplitude of accommodation be engaged when using the eyes for reading or working, or for vocational near vision.

In myopia there are no ciliary complications, except the possible one of weak myopia in young children, below the age of 12, in which it may be neutralized by ciliary tension that slightly flattens the lens. In that case it may be better to prescribe a weak plus lens, thus eliminating myopic asthenopia, and impairing distant vision but slightly, than to take the chance of prescribing a minus lens that does not improve distant vision. But, with the relatively strong and much used circular ciliary fibers, the case is different, quite. These muscles, although comparatively small, are subject to the same influences and show the same effects as other muscles that are subject to continuous tension or strain. The heart, by its beatings, rests between beats, and at least 1/3 of the time. Other organs have their periods of rest distributed to them with as great regularity as their working periods. But the hyperopic eye can have ciliary rest only when we sleep.

Continuous contraction of a muscle, with occasional extra tensions may cause it, in weariness, to fluctuate. If you are already bearing a load, you are more uncertain or unsteady in applying an added tension to the muscles than you would be in starting from a point of rest; and if you hold the weight for some time, you find it difficult to fully relax the muscles that held it. The ciliary muscles may, by strain, suffer a sort of *palsy,* causing them to fluctuate. They are also subject to *spasm* or *cramp,* or inability to relax after being under continuous tension, as in hyperopia. The house-painter's fingers, that have held the handle of a brush all day and plied it back and forth, cannot be straightened again at night. That is spasm or cramp, and he would not be steady-handed enough to write a letter or thread a fine needle. The ciliary is not different than other muscles in this respect.

When the ciliary muscles, the muscles that flex the lens for the exercise of positive accommodation, get into a state of cramp from continuous contraction, as exacted of them in hyperopia, they are not

going to be persuaded to relax by a plus lens that makes such contraction no longer necessary. Therefore the real hyperopia of the eye may be covered up or concealed, and is then termed *latent;* while the part that is relaxed by a lens is termed *manifest.* There is naturally an element between the two, a sublatent or slow-manifest amount that has to be coaxed to come forth and show itself, or to surrender finally to the action of a stronger lens. These elements are independent of what is termed the normal *tone* or tonicity of a muscle, indicating a readiness on its part to respond to stimulation. Hence, the partial spasm that may be drawn out is termed a *clonic* spasm, and that that will not yield is termed a *tonic* spasm. We thus have these hidden influences to deal with in correcting hyperopia in full. This influence also extends to the extrinsic muscles, which cannot be considered at this time.

The medical practitioner has been prone to magnify these concealed factors; but the optometrist is apt to go as far in the opposite direction, and to ignore them completely. There is a middle ground.

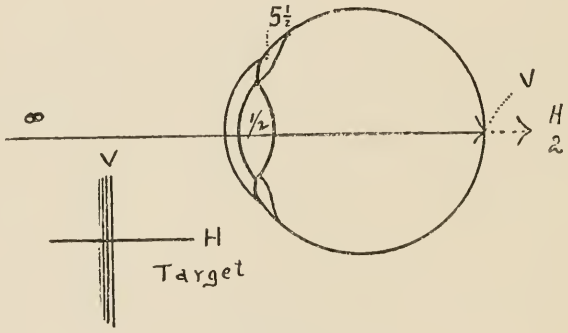


FIGURE 13.

Eye with 2 D. compound hyperopic astigmatism "with the rule" (.50 D. in vertical, 2.50 D. in horizontal); amplitude of accommodation, 6 D.; .50 D. accommodation in use; 5.50 D. accommodation in reserve; V, focus upon retina; H, focus 2 D. back of retina. Horizontal lines of astigmatic chart distinct, Vertical lines blurred.

Repression

Any means that may be employed to relax the ciliary muscles, subject to the influences just described, is called *suspension,* repres-

sion or suppression of the accommodation. Its purpose is to put the ciliary muscles in a complete state of relaxation, so that the crystalline lens will assume its static form, or be at an equilibrium between the opposite pressures of the humors that surround it, and have no special convexity, but be of its normally convex form. As a semi-liquid or humor, the lens has elasticity, for that is a general property of liquids and of matter. But it is nonsense to suppose that, in a state of rest, there is any special tension upon it, due to "draw" of the suspensory ligament when the ciliary muscles are relaxed.

The medical practitioner calls his method, the use of a drug, "suspension" of the accommodation. It would be more proper to term such a method "repression" or "suppression", as it is by the means of influences not of an optical, but chemical character, a method of chemical *violence* that is allowable for surgical or therapeutic purposes, but hardly so for so simple a matter as fitting the eyes with lenses. The optometrist is limited, both professionally and ethically, to the employment of optical means only, the use of lenses for the purpose. But these are the natural and the best means of restoring the accommodation to normal action and relaxation. They never do more than merely relax accommodation. The word "suspension" is the legitimate word for optometry. It releases ciliary tension by taking the ground out from under it.

When a ciliary spasm is indicated, both by a less amplitude of accommodation than normal-for-the-age, by fluctuations of ciliary action, causing alternate clear and dim vision, or inability to maintain steady near vision at any accommodative distance, the optometrist must employ methods that are best calculated to release the ciliary from spasm. He should at least correct all of the manifest hyperopia, and go into the fog as far as he deems it advisable, with the given patient, and feel assured that the lenses will be worn, as directed, constantly. Corroborative signs of latent hyperopia are various, but a tendency to esophoria (apparently real esophoria) is one of the strongest indications. The ciliary cramp may yield slowly, or it may yield quickly, to a plus fogging method; but it will never yield more than the full value of the cramp. There are no *deductions* to be made from the latest finding of a greater for a less plus value.

Astigmatism

Astigmatism is but a combination of different refractive conditions in the same eye, or in different meridians of it, regularly and relatively at right angles to each other. Both may be hyperopic, with one principal meridian more hyperopic than the other; or but one meridian being hyperopic, the other emmetropic or myopic. These are defects of structure that have been considered; the only new thing there is to the astigmatism is the *inequality* between different meridians. This inequality is eliminated by a cylindrical lens that, like a bridge, spans the difference between the two, for the cylinder is of unequal refraction in different meridians, and its inequalities may be made to act as inequalities that are *complementary* to those of the eye.

Being of unequal dioptric power, one principal meridian may have 2 D. greater refraction than the other, as if one has +58 D. and the other +56 D., counting the refraction of both the cornea and crystalline lens, or all the positive refraction of the eye. Both of the meridians have less than the standard power of +58.50 D. assigned to the eye in a previous statement. According to this, both meridians are hyperopic, one for the value of .50 D. but the other for 2.50 D., making the astigmatic difference 2 D. Astigmatism is neither plus nor minus, neither hyperopic nor myopic, but these terms apply separately to the principal meridians, and their difference is the astigmatism.

If the more hyperopic meridian is at 180, and is 2.50 D. hyperopic, while the less hyperopic meridian is at 90, and is but .50 D. hyperopic, a +2 D. cylinder, ax. 90, will make the dioptric power of the horizontal meridian equal to that of the vertical, but both will still be .50 D. hyperopic. On the other hand, a —2 cyl. ax. 180, will cut the dioptric power of the vertical meridian down to that of the horizontal, and both will then be 2.50 D. hyperopic. The correction of the eye is therefore as follows:

1. + .50 sph. C + 2 cyl. ax. 90. or
2. +2.50 sph. C —2 cyl. ax. 180.

But our problem is not "What lens value will correct the eye?", but, without a lens correction, "What will be the effect of the defect

upon the function of accommodation?" Even this depends upon the selection or choice, by the reflex force, of the meridian to accommodate for; and no one can tell in such a case what to do.

If .50 D. spherical accommodation is exercised, the vertical meridian will focus light from test cards at 20 ft. on the retina, and the effect of this will be to sharpen the definition of all horizontal lines in letters or astigmatic chart; but all other lines, especially vertical ones, will be blurred and dimmed. On the other hand, if 2.50 D. of spherical accommodation is exercised, the horizontal meridian of the eye will focus light from 20 ft. on the retina, and vertical lines will become sharply defined, but at the expense of all others, especially the horizontals. The clear images are at right angles to the focalized meridian, whether the accommodation or a lens focalizes it.

In such a case, if the amplitude of accommodation is abundant, the eye is apt to do that very thing. With less accommodative power it may turn to the other meridian, which can be focused with but .50 D. accommodation. The higher accommodation is exercised because the sensory demands at the motor-nerve center are not satisfied with anything else, provided the function will respond to the higher demand. Anything halfway or between the two, would also be unsatisfactory. We have also the natural visual preference for vertical lines, as they always appear to be vertical and parallel; whereas horizontal lines appear slanted, when receding from or approaching the eye.

The above exercise of accommodation is not cylindrical, although it is thought to be by some optometrists who meet it in the fitting room. If the crystalline lens can be flexed cylindrically by the ciliary muscles, it is for a much less amount than the above 2 D. as that would involve a torodial curve that had about 22c more curvature in its maximum than in its minimum meridian, and this would make practically 8 D. astigmatism at the cornea. Whether the eye accommodates cylindrically or not, and for an amount great or small, is beside the question. It may *endeavor* to do so, and then the nervous effects will probably appear, especially if the astigmatism is slight, so that the effort will be encouraged by the near prospect of attaining it. This is not answering the question, which we prefer to

leave as a *mooted* one, as any answer to it would only lead to argument, without any decision.

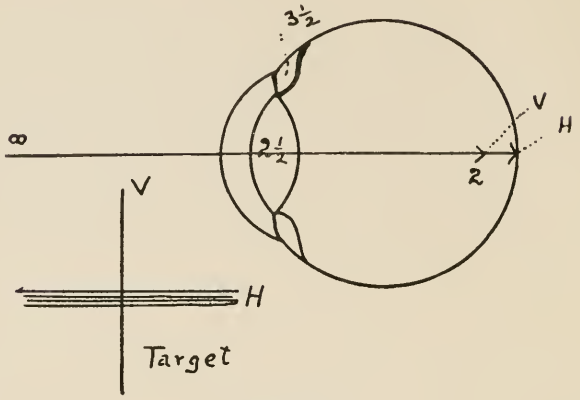


FIGURE 14.

Eye with 2 D. compound hyperopic astigmatism "with the rule" .50 D. in vertical, 2.50 D. in horizontal; Amplitude of accommodation, 6 D.; 2.50 D. accommodation active, 3.50 D. accommodation in reserve; H, focus at retina, V, focus 2 D. forward of retina; Vertical lines of astigmatic chart clear. Horizontal lines blurred.

Hyperopic Induction

Hyperopia and the consequent ciliary activity, exercises an inductive influence on other muscular functions, or motor-nerve stimulations of those muscles, of the eyes. First, the sphincter muscles of the iris tend to contract with the contraction of the circular or the sphincter muscles of the ciliary. Therefore the uncorrected hyperopic eye has usually a small pupil, due to the associated action of these muscles that have analogous functions. But as the two muscles are enervated by the same nerves, the 3rd pair of cranial nerves, and have a common or nearly common, motor nerve-center, that "upon the floor of the fourth ventricle" etc., that is usually ascribed as the reason for their co-ordinate action.

The association of this ciliary action with that of the internal recti muscles, also innervated by the 3d pair of cranial nerves, has already been referred to. This influence is so strong that children who have not fully acquired the "sense of fusion" necessary to due convergence of the eyes for near vision, are apt to over-con-

verge the eyes, or to converge them for distant vision, causing diplopia initially, but leading soon to the "repression" of visual registration in one of the eyes to avoid that result. Unless the hyperopia is soon corrected the deviating eye becomes confirmed in its inward turning, and the eyes are permanently crossed. But the repression of vision in the deviating eye also soon results in its impairment of visual sensitiveness, or to "amblyopia ex-anopsia" or dimness of vision due to the non-use of the eye as a visual organ.

It is thus found that the ciliary activity in hyperopia makes manifest the close association between the ciliary and iris sphincters, and the converging extrinsic muscles, all of which are innervated by the same pair of cranial nerves, but by different branches of them. If the superior and inferior recti are similarly influenced, they counteract each other, and the effect upon the inferior oblique is negligible. This association has, therefore, an anatomical and physiological explanation that is more direct than the association of the radial muscles of the ciliary with those of the iris and with the external recti muscles, which led to the use of the word "induction" to represent their mutual associate relations. But, notwithstanding the lack of a direct nervous connection, at least of a discovered one, the association pertains to the latter quite as evidently, though not so pronouncedly, as to the former. This takes the question to the physiologist.

These associations are of course reciprocal. That is, if ciliary action of either kind influences other optical functions that are exercised by muscles through the stimulation of motor nerves, the exercise of those other muscular functions will influence ciliary action. The entire ocular group of muscles are thus members of the same family and co-operate or co-ordinate for visual purposes.

CHAPTER V.

Vision

Vision is neither a structural nor muscular function, nor is it a faculty of the brain; for faculties, such as reason, memory and the imagination, pertain to the mind, and there are no sensory channels of communication between it and the outer world. It classes as a *special sense,* and is a modification of the sense of feeling or touch.

It is obvious that the eye, both structurally and functionally, is designed to provide the sense of vision with the initial sensory *touch* that is required to set in operation the further sensory activities upon which vision depends. This initial touch is in the form of light-created images at the retina of the eye; and they are placed there by the eye, acting as an anatomical and physiological camera, resembling essentially the artificial camera that images objects by the same means on a ground-glass screen.

It is not in the formation of these images, nor their imposition on the retina, that we have vision. So far as light, refraction and images are concerned, all that is ended at the retina. The retina, optically considered, serves the same purpose as the ground-glass screen of the camera, and no better. It is only the bulletin board on which these images or pictures are drawn. It is what follows this imposition of the images upon it, the *sensory field* on which they are imposed, the character of the spot that is *touched* by them that leads on to the awakening of the visual sense to them. Like the chemically sensitized plate that records the camera pictures, there are, beyond the retina, deeper-seated sensory organisms that respond to and register these retinal impressions, and these are essential to visually *feeling* what the retina displays.

The Retina

Before considering the deeper-seated sensory elements, the retina, as the initial sensory field, must be given first attention. It is a membrane having a vast number of sensory nerve-endings, imbedded in a pigment substance that chemically reacts to light, causing atomic explosions at all points where light touches it. The resulting agitation of the nerve-endings (rods and cones) is communicated to the

brain along a sensory tract, beginning with the retina and ending at the brain. At the optic nerve-head or disc, the retinal nerves, after undergoing important developments within the layers of the retina, are gathered into a cable of sensory nerves and pass out of the eye as the *optic nerve,* where we must leave it for the present to consider the retina itself.

As a membrane the retina covers a little more than half of the inner surface of the eye. Inwardly it is concave, and it is from its outward convex surface that the rods and cones project into the pigmented layer between the retina and choroid coat. Although thin and transparent, the retina consists of ten layers, including the pigment layer into which the rods and cones extend. The sensory qualities of the organized layers is indicated by their differentiation of light waves of greater or less frequency, by which we have color vision; and between convex and concave wave formations, by which the impact of the waves in diffusion circles, locate the foci when forward or back of the retina, thus providing the "guiding sensation" for greater or less accommodation.

On the small area of the retina is displayed the image of every object seen, and it is of these images that the visual sense takes cognizance. Although sensitive to light at all points, except the optic disc, it is specially sensitive at the small area directly in line with the visual axis, known as the macula lutea, as this is the field upon which are displayed the main features of every image on the retina.

FIGURE 15.

Anterior view of the fundus or retina of right eye, showing following details: R, retina as a whole, with arteries and veins; D, optic disc or nerve-head, to nasal side of retina; M, macula lutea, or "yellow spot"; F, fovea centralis in the center of which is located the subjective point of fixation (s.p.f.).

But near the center of this is a small depression, the fovea centralis, that is even more acutely sensitive to image impressions. The subjective "point of fixation" (s.p.f.) is within the very center of this minute area. That point of an object upon which we center vision, the objective "point of fixation", (o. p. f.) is imaged at this very center of the fovea centralis.

Visual Acuity

The term *acuity,* as applied to vision, refers to the "keenness" of recognition of the details of images that are imposed upon the retina. It is a comparative term, and probably depends upon the fineness of texture of the retina, or the compactness and delicacy of structure of the rods and cones, or the responsiveness of the pigmented layer, the "visual purple", to the action of the light. It has no relation to the focalization of light or to the clearness of the image upon the retina. The images are impaired by imperfect focalization, but the acuity of vision is not so impaired. Acuity of vision records, with fidelity, the image as it is, not as it ought to be. The term "20/20" is a record of vision, but not of acuity of vision. The same eye may have had, before correction, but 20/40 vision, although its acuity is not changed by the lens.

Hence, acuity of vision is the capacity of the eye to visualize objects in detail when they are sharply imaged upon the retina, and not what is seen when there are blurred images upon it. But even then people differ, although not enough to prevent the acceptance of a common standard. As we use our eyes mostly for seeing the details of drawings or printed matter, the standard is based upon our perception of letters or characters that make a minimum visual angle at the eye, and therefore have a retinal image to correspond to it, for the visual angle that embraces the object also embraces the image of the object upon the retina. As there must be a contrast between the image and its background, there must also be a corresponding contrast between the object and its background. Therefore black letter or figures on a white background are the accepted requirements.

To meet the accepted standard of size required for clear visual delineation, the object size must be sufficient, for its distance from the

eye, to make the minimum angle of vision equal to 1′, or 1/60 of a degree. In a "block letter" whose segments are in the ratio of 1 to 5 to the whole letter, the entire letter must fill a visual angle of 5′, or 1/12 of a degree. To recognize, visually, letters of this size, the smaller segments must be seen, so that recognition of the letter involves seeing its segments. The easiest way to calculate the size of a letter for any fixed distance is on the basis of the tangent value of a 5′ angle, which is .00145. This is the ratio of a full dimension of the letter to its distance from the eye. Hence, for a distance of 6 meters or 6,000 millimeters, it is .00145 of 6,000 mm. = 8.7 mm., or for 4 meters it is .00145 of 4,000 = 5.8 mm.

As 6 meters is practically a distance of 20 ft. letters of the above dimensions, 8.7 mm. tall or wide, or both, are designated, in the line of letters of that size, line-20. Hence, if the letters of the line can be read off at 20 ft., vision is said to be 20/20, or normal, according to the standard. In a letter chart letters are made of normal size for different distances, as for 30 ft., 40 ft., 60 ft., 100 ft., etc., and these lines of letters are termed line-30, line-40, line-60, line-100 etc. When a patient can only see the letters of line-60 at a distance of 20 ft., vision is designated at 20/60; but this is not visual acuity, as many term it, but merely "vision", although the eye may not be able to see better with a lens correction, for that question has not been deter-

FIGURE 16.

Foveal vision of the crescent of the new moon, the lower horn of which is the objective point of fixation. This places the image of the other horn near the border of the fovea.

mined. The acuity of vision is as good as it can be made with a lens correction.

Foveal Vision

We gauge visual acuity by what the eye can see at its most sensitive area, the fovea centralis, which is said to be supplied with cones only as nerve endings, or to be without the less delicately sensitive rods. To give an idea of what would be embraced in a foveal image, we may refer to a statement of Tscherning, to-wit: that when we look at the crescent of the new moon, and fix one horn of it, thereby placing its image at the "subjective" point of fixation at the center of the fovea, the image of the other horn is also on the fovea, but nearer its margin. As the diameter of the moon is 2,160 miles, and its average distance from the earth may be taken as 240,000 miles, the tangent value of its angle of vision at the eye is the former divided by the latter, or .009, which represents an angle of 31′.

Allowing 3′ extra for the uncovered margin, the angular space separating the center of the fovea from its margin is 34′, and this is but half of it, and therefore the whole is approximately 68′, whose tangent value is almost exactly .02. With this ratio as a basis we may calculate the size of any object whose image would be embraced upon the fovea, if we know its distance from the eye; or the distance at which an object of a given size would have to be to have its image embraced by the fovea. On this basis, taking 17 mm. as the focal-length of the eye, the diameter of the fovea is .02 of 17 mm. or .34 mm. = practically 1/3 mm. or radius of 1/6 mm. In the Snellen test cards, at 20 ft., or 6,000 mm., a circular space of the diameter of .02 of 6,000 = 120 mm., would be included in it. In the supplementary figure we show what letters of line-20 would fall upon it when the letter in the center of line-20 is fixed. We see only that one letter by *direct* vision; all of the others are seen by *indirect* vision. It is the one letter we are concentrating visual attention upon.

If, on the street, we look at objects half a city block away, (660 ft. for a full block) the images included in the foveal area would be .02 of 330 ft., or 6.6 ft. Therefore a six-foot police officer at that distance might be imaged upon the fovea, if we directed attention to a silver buckle on his belt. But we could also see many details of

his uniform, for there is quite a difference between a .02 and a .00145 angle, the latter being the tangent of a 5′ angle, the former of a 68′ angle. For the given distance, the 5′ angle would embrace practically 5¾ inches. Therefore the five-pointed star on his uniform if of this size, would be seen in detail by one with normal vision. This would be the same as looking at objects through an aperture in an opaque disc. At the reading distance of 1/3 meter or 13″, the aperture would require to be .26 of an inch, practically ¼ inch, or 6 mm. in diameter. Hence, in reading at the reading distance, the latter is the extent of the images that are depicted on the fovea centralis at one time.

Fixation

In reading the test type at twenty feet, we fix but one letter at a time out of line-20. The remaining letters of the line, if the fixed letter is the central one, may be upon the fovea. Our diagram rep-

FIGURE 17.

Foveal vision of the portion of a Snellen test card, as seen at 6 meters, when the central letter "Z," or its middle segment, is the objective point of binocular fixation reduced not quite one-half.

resents the letters as they visually appear, not the foveal image of them, for that is an inverted image, and the same is true of the crescent of the new moon and other figures. We have direct vision of but a small area of any object, but it is something more than a mathematical point, which is without area. We may say that the standard minimum "physical" point we can fix (either with one or both eyes) is the 1′ minimum angle, such as the middle segment of the capital letter "E" in line-20 at 20 ft. When vision is below normal, as 20/40, it may be taken as the corresponding segment of a letter from line-40, for one cannot have fixation of what he cannot see, either monocularly or binocularly. Fixation involves three essentials, to-wit:

1. Directing the visual axis to the objective point fixed, so that its image will fall upon the subjective point of fixation, at the center of the fovea.
2. Engaging visual attention upon it, making the visual sense alert to the object being visualized, rather than points nearer or farther on the same axis.
3. Accommodation of the correct amount to make the image, whatever the distance of the object, as perfectly defined as possible.

The first two items may be considered voluntary; but the third is involuntary; but by doing the first two voluntary things, the third will naturally co-operate with them by reflex action. We may direct the visual axes where we will, and engage visual attention upon what we choose, be it far or near. But, having done so, the accommodation does what is required of it to the best of its ability. For binocular fixation, something more is required.

Visual Axis

The visual axis is a line connecting the subjective and objective points of fixation. Objectively considered, the "point of fixation" is in the object, and an axial ray of light passes from it to the center of the fovea centralis. It is too near the optic axis to suffer but the slightest refraction at any surface, and is therefore a straight line. Other rays of light from the same point suffer slight refraction, for they are converged to a focus at the retina, or at the

subjective point of fixation or foveal center. But, subjectively considered, the visual axis is a line of projection merely, extending from the subjective point of fixation out into space, and to the objective point. It is not light and therefore suffers no refraction, nor are there any side rays to be refracted although we may have, theoretically, such a pencil of rays; and actually do have them in shadow-testing an eye.

Regarded subjectively, it is the retinal image of the object we see that is the original manifestation in any visual sensation. The object, visually regarded, is a projection of the retinal image. But all of our experiences in the physical world teach us that, for such a sensation, there is an objective physical cause. The retinal image of a vicious dog could not bite us, nor the retinal image of a speeding automobile run us down. Nevertheless, when we receive these retinal sensations or warnings, we endeavor to get out of danger, for we know that any on-looker might otherwise have the visual sensation of a dog biting a man or an automobile running him down and injuring him. We therefore dismiss this vague theory of subjective originality and consider the real things by which we are so evidently surrounded and the light that makes images on the retina as the basis for visual sensations.

When we look through a wire netting or screen at objects beyond it, by fixing a particular object we direct the visual axis to it, the visual sense is made *alert* to it, and the accommodation focalizes the light from it and images the object upon the retina. The image is an inversion of the object, but the object is also an inversion of the image. The latter is objectively the *real* thing. But the image is also real. Which of the two is inverted depends upon our point

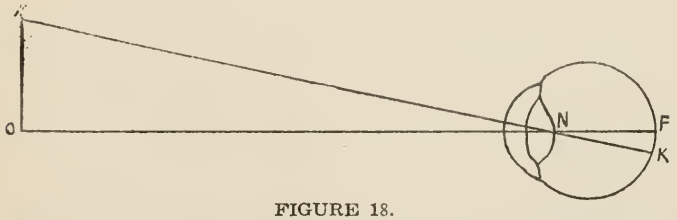


FIGURE 18.

Representing the "angle of vision," visual axis, points of fixation, and other details; O, objective point of fixation (o.p.f.); F, subjective point of fixation (s.p.f.); OF, visual axis; ONH or FNK, objective and subjective "angle of vision"; N, posterior nodal point of eye.

of view. We prefer to regard the whole matter from the physical standpoint, that it is the object that is real, and that the image is but an inverted picture of it in miniature. While we are visualizing an object through the screen, we have a shadowy definition of the wire netting imaged upon the retina. The visual axis passes through it to the object on which attention is fixed; but our visual sense is not alert to it, and we are not therefore accommodating for it. But, we may, in a moment, fix attention upon the wire, and withdraw it from the object beyond it. Then, although there is no change in the direction of the visual axis, the accommodation at once focalizes the light from the wire netting at the retina, and our vision of the object beyond it becomes shadowy and indistinct, although we may still see it by indirect vision.

Indirect Vision

Direct vision is our means of scrutinizing the details of an object, and we do that by fixing successively its different objective points or features, and in such rapid succession that we visually grasp the whole, or an area much wider than the fixation point. But the initiative for turning visual attention from one point to another, and the visual axis from one direction to another, is the *indirect vision* of those other points of interest embraced within our entire field, and to which we may presently turn visual attention for greater details, or for a more detailed inspection of them. This applies not only to lateral points, to points in all directions from the point of fixation, but to points farther away or nearer to the eye. Vision is thus kept perpetually on guard and indirect vision plays a not less important part than direct.

The images of objects being seen by indirect vision are placed on the retina by pencils of light that pursue a course oblique to that of the light from the point of fixation. But these pencils have an axillary ray or one whose course, after refraction by the dioptric media, is parallel with its incident course, and it is a secondary axis unless it happens to be that ray that is known as the *optic axis,* and which pursues its course to the retina in a mathematically straight line. But, it reaches the retina slightly to the nasal side of the subjective point of fixation, at the center of the fovea. Or we may say,

that the visual axis is slightly oblique to the optic axis, as the point of fixation at the retina is slightly to the temporal side of the posterior pole of the eye. It is this position of the fovea and of the macula that provides the theorist with those intangible angles, the angle *a* or *alpha*, and angle *gamma*, the latter being purely hypothetical.

Cardinal Points

It is these angles also, as well as the proportion of refraction of the different dioptric surfaces of the eye, due to differences in curvature and index, that locate, along the optic axis those points that are known as the cardinal points of the eye. They are respectively:

1. The Anterior Principal Point.
2. The Posterior Principal Point.
3. The Anterior Nodal Point.
4. The Posterior Nodal Point.
5. The Anterior Principal Focus.
6. The Posterior Principal Focus.

As these technics have really nothing to do with the visual axis, and it is the line of greatest interest in the study of the muscular functions, we can leave them to the mathematician who loves to delve in abstractions rather than direct his attention to the matters of real concern, and that have a practical value to those who may read this book, which we hope to make useful rather than ornamental.

The Sensory Tract

At the optic nerve head or disc, which is about 1/10 diameter of the eye to the nasal side of the posterior pole of the eye, the sensory nerves from the retina are gathered into a single cable, and pass out of the eye as the *optic nerve*. But, in the optic nerve, they do not lose their identity, but remain distinct, the same as the wires in a telephone cable. The optic nerve passes back through the orbit to the optic foramen, and through that aperture into the skull. It then extends to the optic commissure or chiasm, at which it undergoes an important division and reclassification.

First, there is a division of the optic nerve into two branches, one of them embracing all of the sensory nerves from the right half

of the retina, and the other all of the sensory nerves from the left half of it. As there are two optic nerves, one from each eye, branching in this manner, to get those nerves together that are from corresponding areas of the two retinae, one division of each nerve must cross to the other side. Hence, that division of the right optic nerve that embraces nerves from the left half of the retina of the right eye, and that half of the left optic nerve that embraces nerves from the right half of the retina of the left eye, cross over at the chiasm, and join the other half of the nerve cable remaining on the same side as its origin at the retina. The two reclassified cables then proceed to the right and left hemispheres respectively, of the brain, as the right and left *optic tracts*.

The sensory effect of this classification is to give each eye sensory connection with both hemispheres of the brain, for the right half of the right optic nerve extends to the right hemisphere and the left half to the left hemisphere; while the right half of the left optic nerve extends to the right hemisphere, and the left half to the left hemisphere. If we may speak of the brain as "seeing" the images depicted on the retinas, the right brain "sees" what is depicted on the right half of the retinas of each or both eyes, while the left brain "sees" what is depicted upon the left halves of the two retinas. Hence there is two-brain vision of the entire image upon each retina; or the entire images, single at the retina of each eye, are duplicated in brain vision of them. Naturally we might expect to see doubly, or have double vision, and sometimes we do, greatly to our annoyance and distress. This, even, is binocular vision, but not the most acceptable kind.

Binocular Single Vision

The right eye has a complete image of the objects before it, and the sensory reaction of this image is conveyed to both brains, the right to the right brain, left to the left brain. But the two half pictures are dove-tailed together with such nicety that you do not suspect it, as the two brains are most efficiently connected by a sensory union. The entire image on the left retina is visualized in the same manner. But, since at the chiasm, all the sensory nerves from corresponding sides of the two eyes, right for right and left for left, are

joined together in the optic tracts, they go together as one sensory registration to the brain, provided every rod or cone in the retina of the right eye, or its sensory nerve extension to the chiasm, *finds* there, or at some point farther on, the sensory nerve from a corresponding rod or cone of the retina of the left eye. It is the crossing over or decussation of nerves at the chiasm that has made this finding, and their joining before the sensory report is turned in at either brain, possible. But if there is no such joining made, two sensory reports are registered, and vision is unavoidably doubled. Hence the necessity of optically placing the two images on corresponding points of the two retinas.

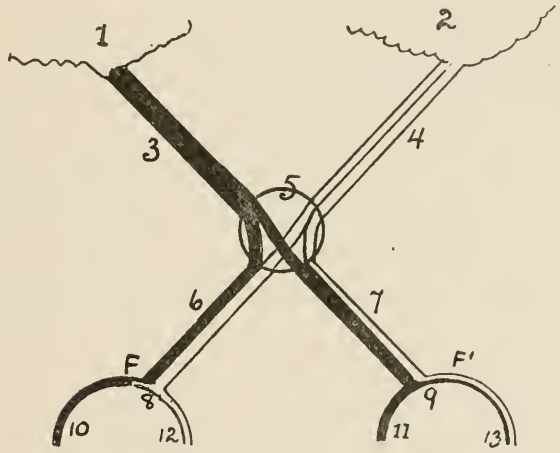


FIGURE 19.

Double sensory visual tract from retinae to brain: 1, right hemisphere of brain; 2, left hemisphere of brain; 3, right optic tract; 4, left optic tract; 5, chiasm or optic commissure; 6, right optic nerve; 7, left optic nerve; 8, right optic disc; 9, left optic disc; 10, right half of right retina; 11, right half of left retina; 12, left half of right retina; 13, left half of left retina; F, fovea of right eye; F', fovea of left eye.

Such sensory union of the two retinal images is termed *fusion* of the images; and fusion of the images gives us *single* vision of a single object, notwithstanding its duplication on the retinas of the two eyes. But the two images must be so placed upon the two retinas as to fulfill the requirements for a single sensory report or reg-

istration of every point in the object that is thus duplicated in the retinal images. It is at the brain that these sensory reports are intercepted. We must therefore be provided with the means of either *moving the images* to corresponding positions on the two retinas; or *of moving the retinas* to corresponding positions of the two images. For the first, our only means of getting the images together when they are not normally so, is to divert or alter the course of light from the object, for one or both eyes, which would require artificial agents. But, for the second, our means is by rotating one or both eyes in their orbits to corresponding relative positions, and this is where the extrinsic muscles of the eyes function very importantly.

The union of the two images into one, or fusion, cannot take place except at the visual center of the brain, but the sensory basis for it may be regarded as occurring at the chiasm, where, if the corresponding sensory nerves are not actually united, they are effectively joined at that point, for the classification of nerves that puts them into a single optic and sensory tract does occur at the chiasm. No one can say at what exact point these sensory things are transmuted into vision, which is a psychic rather than sensory manifestation, a *miracle* rather than a natural phenomenon. To the brain is as far as we can go in the investigation of its causes and effects, and so far, we have dealt only with the sensory effects, and avoided the term "vision" as far as it could be avoided and express the thought we had in mind.

Normal Violation of Rule

The above "rule of correspondence" of the images is a visual one, a visual requirement for the fusion of the images and for binocular single vision. But here a law of optics interposes and blocks this visual rule, and makes the strict fulfillment of it impossible, except for a single point of the object, the o. p. f. or objective point of fixation. The two eyes receive light from any object before them from slightly different directions, so that the two retinal images cannot possibly fall upon exactly identical or corresponding points of the two retinas over their entire area. In looking at the upright trunk of a tree that is clearly seen binocularly at a distance of 20 to 30 feet, the right eye will see farther around it to the right than

the left eye; while the left eye sees farther around it to the left than the right eye. The retinal images differ from each other in the same way, and to the same extent, so that this is an optical block to the rule of correspondence.

But all of the points of the object, except the point of fixation, are seen by indirect vision, and indirect vision is, as we have seen of a shadowy and less exacting character than direct vision. As the object seen is visualized as one object, notwithstanding this obvious and immutable optical law or principle, it is manifest that the rule of correspondence exacts no such impossibility, but is satisfied with

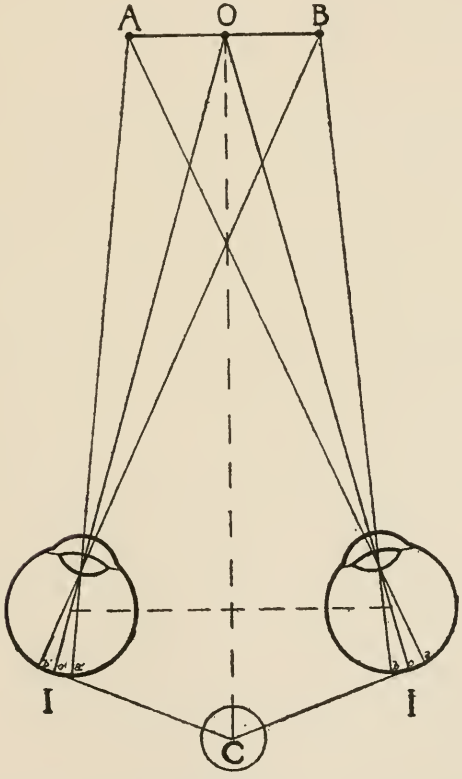


FIGURE 20.

Binocular fixation of the point O, in the line AOB. The image of A, B and O are at a and a′, b and b′, o. and o′ respectively in the right and left eyes, or upon the retinae.

exact correspondence for the s. p. f.'s, or subjective points of fixation, and the visual sense will fuse the images if they stand in this relative position, and overlook or disregard violations of it in fields of indirect vision. Therefore, points indirectly seen do not fulfill the rule of correspondence, nor can they, from the nature of things, be made to do so without themselves becoming the s. p. f.'s, or vision being turned to them as the new points of fixation, and taking the place of the o. p. f. previously fixed.

But this "permit" we may call it, to violate the rule of correspondence, is not a license to do so to any degree except only for the amount that the optical law imposes upon it, and it may therefore be termed as above, a *normal violation* of the rule.

Stereoscopic Vision

It is often said that "there is no great loss without some small gain", but this is an illustration so often furnished by optics and vision, of a very great gain at a very small loss, if it is a loss at all, for it is the violation of the rule of correspondence at all points, except the one point of fixation, that provides us with *stereoscopic vision,* or makes it possible to visualize distance, as well as the form and color of objects. That is, we are not only able to see them, in due form and color, but we can definitely see their relative positions and our own position relative to them. This is what is termed *orientation.* But the visual setting of a vast number of objects in due position, relative to each other, as they are arranged in any natural scene, we call the *perspective* of the picture, and stereoscopy of vision contributes mightily to these visual qualities.

The degree of violation of the principle of correspondence, by the optical law, depends upon the distance of the indirectly seen objective point from the point of fixation, or o. p. f. When we binocularly fix any objective point, the visual axis of each eye extends from the s. p. f. of each eye to the one o. p. f.; or light from the one o. p. f. proceeds directly to each s. p. f. of the right and left eyes, as shown in an accompanying figure or diagram. While the two eyes are thus fixing this one objective point, all other points are seen by indirect vision. The two s. p. f.'s will visually coincide, but the violation of coincidence at all other points of the retinas will depend

upon their distance or distances from the s. p. f. of the eye or retina on which they are displayed as images; and this, for any single object, depends upon its nearness to the eyes. The farther the object is from the eyes, the nearer all points of it or of their images, will cluster around the s. p. f.'s, for the images will be smaller; and the nearer the object to the eyes, and therefore the larger the images, the more its objective points will be spread out in the image, and the greater their violation of the rule of correspondence, or augmentation of space separating the images of corresponding points of the object.

We are thus provided with the visual gauge for judging the distance of an object, or the relative distances of two objects, or whether the object that is moving before us is approaching or receding from us, and at what velocity or speed. It is not an absolute measurement of distances, but a visual one; but it sets the array of objects in any natural scene before us in perspective, which is often a part of its beauty, and sometimes a feature of its ugliness, so that we may know what to court and what to avoid, in feasting our eyes on the beauties and uglinesses of nature. No art, except an art that involves real vision as a finality, can contribute to our pleasure or distress in such matters; but with that finality, there are many ways of enhancing vision and of recording and preserving what we have once seen, although never, except in the case of memory or the imagination, with the fidelity and vividness of the original vision of the same objects.

Our retinas are in the nature of "moving picture" screens, recording in brief displays all that is going on around us. To change the view it is only necessary, without moving our bodies, to change the general direction of vision. By a short walk we can greatly add to the variety of the things seen. By travel this variety is greatly increased, and all we see is seen binocularly, stereoscopically, in perspective, and both stationary and moving objects appear as they are, and even any movement we may make that shifts the scene is recorded with the same accuracy. All of which goes to show that we have with us always, in binocular vision, a moving picture program very much superior in operation and display to any we pay from 10 cents to as many dollars to see on canvas. Why, then, the

craze for moving pictures? It is entirely on account of *what* we see at them. We cannot go out and see a man falling from an airplane, an explosion at a factory, an automobile collision, or a complete drama, with all characters moving about as on the stage, whenever we wish to. The Moving Picture Show provides us with these diversions, and so we go to them and cheerfully pay the price of admission, including the tax as well as the taxi, to get us to and from it.

We have other means than stereoscopic vision to judge the distance of an object by, as the convergence of the eyes required to fix it, and the accommodation of the eyes required to focalize it. But these are the mere exercise of the muscular functions of the eyes, of which we are unconscious, and there are other factors than distance to affect them. On the other hand, stereoscopic vision is a *visual* manifestation. A hyperope doesn't know that he accommodates when looking at distant objects; nor that he accommodates more when looking at near objects, nor that he converges the eyes more or less for either. These things are done involuntarily and unconsciously. But the stereoscopic effects of distance manifest themselves to his vision, although he may not be conscious of the underlying causes. The scene displays itself before him and he takes it in, nor can he rid himself of the visual manifestation of it, unless he does so voluntarily, by closing or obscuring one eye. Even then, the preceding binocular effects remain with him, as the images do not fade at once, but linger in the visual sense.

Image Displacements.

We tolerate, without serious impairment of fusion or single vision, many and often quite serious differences of the two retinal images, and see the object better with both eyes, one image being much clearer and better seen than the other, than we can see it with the better eye alone. These differences may be due to differences in refraction of the eyes, to differences of visual acuity in them, to differences of accommodative power, for these may not disturb the visual fusion of the s. p. f.'s, and we are accustomed to differences at other points. But, a relative misplacement or displacement of the two s. p. f.'s, which at once gives double vision, is profoundly dis-

turbing, disagreeable and intolerable. The ocular muscles at once attempt to relieve this intolerable visual effect, to bring these two subjective points together by rotating the eyes to a proper relative position. If they are unable to do so, we repress or suppress the sensory reception of such image, fixing our visual attention on one of them alone, and allow the other, or force it, to keep in the background of the visual sense.

The muscles, when so engaged, do not move the images, but bring the retinas to the proper relative positions. This may require a rotation of but one of the eyes. But as there is a natural inclination of the two eyes to rotate together in the same direction, such a rotation of one of them, with the other remaining stationary, may be impossible; or if it is possible, the fixing eye must be held to its normal position while the rotating eye is turned into its position to correspond with it, so that the stationary eye is put under as great muscular tension to retain its normal position, while the other eye rotates to it, as the rotating eye to be brought into correct alignment with its binocular mate. Therefore, such muscular tensions for the

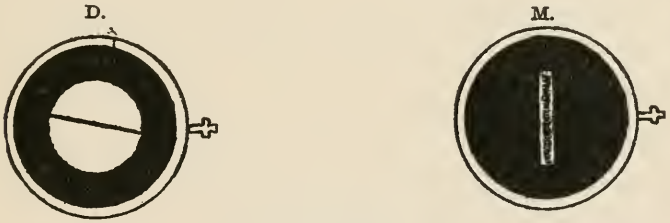


FIGURE 21.

Devices employed to deceive vision and eliminate stimulus of visual sense for fusion of the images. D, double-prism, the central line showing position of bases of prisms; M, Maddox rod, single form, with an oblong aperture in disc for mounting. Horizontal rods make single light into vertical streak.

purpose of bringing about fusion, are *always* binocular in character. They are participated in by both of the eyes, or by the muscles of both, and equally by the two eyes or by their muscles. This fact is as elementary or fundamental as the fact that 2 and 2 make 4. They are the pairs of muscles that rotate the eyes in opposite directions.

But the muscles may be relieved of this action by employing *prisms,* or a single prism before one eye, to so direct the course of

light as to place the images in the relative positions of fusion, thus saving the muscles the strain of rotating the eyes as required. A prism of the correct value to unite the two images may stand before either eye, but its required direction of deviation for the right eye must be exactly opposite to its direction of deviation for the left eye. It moves the image to where it requires to stand to fuse with the image in the other eye. A prism, since it satisfies the demand for a fusion position, is a binocular optical agent. In any means that may be employed to fuse images, muscular or prismatic, even though the muscle rotates but one of the eyes or the prism moves the image in but one of them, we are optically dealing with both of the eyes, and one as much as the other.

Visual Deception

To cause a pair of eyes to reveal their true muscular condition it is necessary to eliminate, in some manner, the natural desire that the two similar images be fused into one, and so quiet the muscular stimulation needed to satisfy the fusion sense. We do this by employing a device that makes one of the images dissimilar in color, form, position or number from the other. Only one of the eyes needs to have its image so treated. The devices most used are as follows:

1. The *Single Prism,* with any small target, as a line or letter on a distant chart.
2. A *Double Prism,* with the same target as above, or the line-and-dot at any convenient distance.
3. The *Maddox Rod,* with a small bright light at 20 ft. as target.

A colored disc is sometimes used with either of the above, or by itself. The Pyramid device is a development of the 2d, and the Cone device is a development of the 3d. These devices, placed in a trial cell, may be rotated to any position desired.

The Single Prism, placed before one eye, so displaces the image of the target that double vision is unavoidable. We may then observe what relative positions the two images have, and ascertain whether there is a muscular factor operative tending to separate them.

The Double Prism produces diplopia of the eye over which it stands. The positions of these two images, relative to the single one in the uncovered eye, then tell what the muscular tendencies of the eyes are, normal or abnormal.

The Maddox Rod converts the small bright light into a straight lineal streak of light, and the single light, seen by the uncovered eye is directly in it or not, according to the muscular condition of the eyes. Its direction from the streak indicates the abnormality.

CHAPTER VI

Axillary Control

Since the visual axis of an eye extends from the center of the fovea centralis out through the dioptric media into space, it is fixed in position relative to the eye; but rotations of the eye in its orbit give it a different direction, so that its other extremity may be changed as desired by such rotations. The objective point on which vision is, for the moment, centered, is at its objective extremity. It is therefore a line extending from the subjective point of fixation, s. p. f., to the objective point of fixation, o. p. f., and maintains that character for all directions.

In binocular vision there are two subjective points of fixation, one for the right eye and one for the left. But there can be but one objective point of fixation, even with diplopia or double vision, as "fixation" involves

1. Directing the visual axis to the objective point.
2. Adapting the accommodation to its distance, and
3. Visual alertness to the object visualized.

In diplopia, visual attention may be fixed upon either of the two objects that appear. The eye that fixes it sees it by direct vision, the other eye sees it by indirect vision. But we may reverse this by giving visual attention to the second of the two objects seen. In binocular single vision both eyes at once meet the above requirements. The two images are then *fused*, at the retinas, at the chiasm or at the visual centers of the brain.

As we live in a moving world, and ourselves move about in it, it is quite essential that we have the means of adjusting the positions of the visual axes, both to the different directions of objects from the eyes, and their different distances from us. The first is required by each eye singly, the latter by the two eyes as binocular organs, for an objective point cannot be in exactly the same direction from both of the eyes, especially when we are near to it. For near objects it is necessary that the eyes be converged to the one point of fixation. It is a physical as well as a visual necessity.

We are able to change the direction of a visual axis by changing the position of the head, or by tilting it up, down, to right and to left; we can also move the body so as to change the direction of the visual axes. But these movements would be too slow and uncertain for us, and we cannot converge the eyes by either a head or body movement, as required for near vision, nor to prevent diplopia when the eyes or their axes are not in true alignment for binocular single vision. Orbital rotation of the eyes provide this scope of movement.

Mountings and Muscles

Each eye is enclosed in an open-mouthed membranous sac, the Capsule of Tenon, in which it may rotate freely within certain limits, but is restrained from turning too far by check ligaments that cross from it to the inner surface of the capsule. The cornea and forward part of the sclera are exposed at the anterior opening of the capsule to air and to incident light. The eye, as thus enclosed, is set or mounted in the socket, and protected anteriorally by the lids, which may be closed down over it, and the eye-lashes.

But to provide for its rotation in its orbit, each eye has six extrinsic muscles. These are arranged in three antagonistic pairs, so that for any direction of rotation there is a motor muscle and a check muscle, giving complete control of its movements or for holding it in any required position. These antagonistic pairs of muscles are so arranged that each pair rotates the eye on one primary axis of rotation, such axes being at right angles to each other, and the two muscles of a pair rotating the eye in opposite directions.

Horizontally, the eye is rotated rightward or leftward on a vertical axis of rotation by two opposing muscles, the internal and external recti muscles. Vertically, it is rotated upward or downward on a horizontal axis by two opposing muscles, the superior and inferior recti muscles. Torsionally, it is rotated or twisted with or against the direction of the clock hands by two opposing muscles, the superior and inferior oblique muscles. Each eye is supplied with a full set of these muscles, arranged as described. But by a combination of the different pairs, it may be rotated in any direction or on any axis of rotation.

The muscles are all of the longitudinal variety and attached or inserted at one extremity to a cartilaginous process of an orbital bone, and this is its stable anchorage. At the other extremity it is attached to the eye by thread-like tendons. The four recti muscles and the superior oblique have their anchorage at the posterior aperture, the optic foramen, or to a cartilaginous ring that surrounds it. The four recti muscles extend forward, over or around the eye-ball, and are attached to the eye-ball just back of the corneal border. The superior oblique passes through a cartilaginons loop, or trochlea, at which it is deflected over the eye near its equator and is attached to the temporal side of the eye-ball. The inferior oblique is anchored to a nasal bone of the orbit and passes under and around the eye to its temporal side where it is attached to it. The superior, inferior and external recti and the inferior oblique muscles are supplied by branches of the motor oculi or 3d cranial nerves, the superior oblique by the 4th and the external recti by the 6th nerves. But there are motor nerves from the cervical vertebrae that influence these muscles. It may be that there are even other unsuspected sources of innervation and all are subject to the "inductive" influences of the intrinsic muscles, as well as the latter to the former.

Binocular Pairs

The most important pairing of the ocular muscles is their binocular arrangement into pairs, and such pairing depends upon whether the binocular rotations to be effected are in the same or in opposite directions. To make these classifications clear, rotations of the eyes in the same direction, and for equal amounts, are termed *Versions;* but rotations in opposite directions, also for equal amounts, are termed *Ductions.* But since muscular force is often applied to the eyes for the purpose of preventing rotations, the terms are used to indicate the muscular tensions, rather than to the rotations. The object of the versions is always to widen the field of vision; that of the ductions is always to fuse the images, or put them in the correct relative positions for fusion. They would be defined as follows:

1. *VERSION:*

   That *voluntary* muscular action that normally rotates the two eyes equally in the same direction.

2. *DUCTION:*

That *involuntary* muscular action that normally rotates the two eyes equally in opposite directions.

With respect to the rotations of the eyes, since either a version or a duction, to be definitely recorded, must have a starting point or datum, it is important to note that, for the versions, the datum or data are naturally the *Medial Planes.* But, as the ductions are strictly according to the relative directions of the visual axes, and their parallelism is the primary relationship for viewing distant objects, *Parallelism of the Visual Axes* is the datum for the ductions. This does not imply that, when the visual axes are parallel, there is no duction force being exercised, for a duction or a version is the muscular tension exercised for a given rotational movement, and not the movement itself.

The Medial Planes

To be made the datum for rotations of the eyes, versions or ductions, the medial planes must be of a stable position, at least as far as they can be made so. We therefore regard them as pertaining to the bony orbits of the eyes, rather than to the mobile eyes. It is assumed further that they pertain to these orbits when the head is erect, and at normal poise on the neck and shoulders, so that the eyes are in the normal position for straight away vision. These planes are then located as follows:

1. The VERTICAL Medial Plane is vertical and bisects the horizontal straight line connecting the centers of rotation of the eyes.
2. The HORIZONTAL Medial Plane is horizontal and passes through both centers of rotation of the eyes, such centers being supposed to coincide with the orbital centers.
3. The INTERORBITAL Medial Plane is at right angles to each of the other two. It may pass through both centers of rotation of the eyes, or be moved forward to any position.

The 2d as well as the 3d is interorbital, and the 3d as well as the first is vertical, but these are subordinate features of them. As they all pertain to the orbits, rotations of the eyes in the orbits do not

affect their positions. Inclinations of the head or body would do so, but we regard them as fixed in the positions described whatever the movements of the head or body. The eyes may be considered as having medial planes, but the medial planes of the eyes are of no value as data to indicate movements or tensions. The eyes may be rotated to the right or left, up or down, or torsionally, with reference to these planes, and such movements are "versions" if equal and in the same direction; but they are "ductions" when equal and in opposite directions.

Primary Position

The primary binocular position of the eyes is that position in which the visual axes are parallel with each other and both are parallel with the 1st, coincident with the 2d, and perpendicular to the 3d medial plane as above described. But this is a position merely without regard to what muscular tensions may be necessary to fix the eyes in that position, or how great or little muscular force will be necessary to rotate them out of it. If they are forced into that position by muscular action, the term "orthotropia" is sometimes applied to it, but as it is a self-contradictory term, it is not much used.

But, if the above described primary position is maintained easily and comfortably, without special tension on one pair of the extrinsic muscles more than any other pair, or is the position of muscular rest, the eyes having no tendency to turn out of it, either versionally or ductionally, we use the term *"Orthophoria"* to describe it, and that

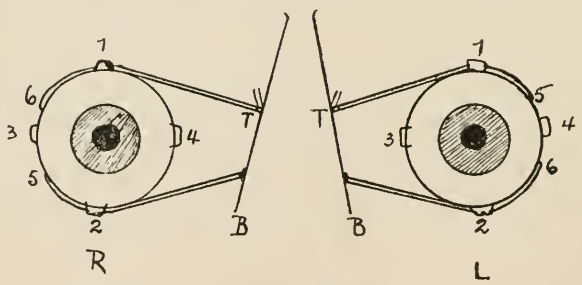


FIGURE 22.

Diagram of attachments of muscles to eyeballs, arranged in version pairs by number: 1-1, Hyper-version pair. 2-2, Hypo-version pair. 3-3, Dextra-version pair. 4-4, Sinestra-version pair. 5-5, Right-tor-version pair. 6-6, Left-tor-version pair. R, Right eye. L, Left eye. T-T, Trochleas. B-B, Nasal bones.

is a significant and appropriate term to apply to it. It is normal muscular balance or poise of the eyes. The primary position is the position the eyes naturally tend to assume when all of the muscles are equally relaxed. It corresponds to the term "emmetropia" as applied to the refraction of an eye relative to its axial depth, something that cannot be improved upon, but it is a binocular term, whereas emmetropia is a monocular term.

It is not to be supposed that, because of orthophoria, all muscles are of a standard length, or that their attachment to the eye-ball is at some standard fixed point, or even that opposing muscles are perfectly equal in all respects. But if any muscle is relatively long, or is attached relatively too far forward or back upon the eye-ball, there is an equal but opposite malattachment of its opposing muscle in the other eye, so that the *net* result, or the *combined* effect, is such as to balance the two eyes. There is no such anomaly as a monocular imbalance of the muscles. The term, and other terms of the same character, refer to the relationship of the two eyes, not to their individualities.

Functional Activities

Given then a pair of orthophoric eyes, the only thing to consider about their muscular duties is in the exercise of their normal functions, and these are their versions and their ductions, both of which are exercised by the same muscles, but in different arrangements of pairs; and both of which are stimulated by the same motor nerves, but upon an entirely different principle, the versions being voluntary, the ductions involuntary. The tracks of a railroad point out the direction the train is to proceed; but the switchman controls the track it must proceed upon, whether parallel to the main track or in an angular direction from it.

Normal Versions

With respect to terms, or the nomenclature of ocular movements or muscular tensions, there is a somewhat confusing array of terms that would be applicable. But, notwithstanding that fact, there seems to have been selected, in many cases, the wrong term for a given action. Names are not of much account except as representing ideas, and even an inappropriate name is better than none, so we

won't quarrel over so simple a question as "What shall we name the baby?"

1. *HYPER-VERSION:*

   This is that voluntary muscular action that normally rotates both eyes equally upward; or may restrain them from turning in that manner downward.

2. *HYPO-VERSION:*

   This is that voluntary muscular action that normally rotates both eyes equally downward; or may restrain them from turning abnormally upward.

In either case, we may take the action or not, as we choose. If we have no interest in the air-plane that is purring above our heads, we are not compelled to turn the eyes upward to see it. We can let it go to some other day if we want to. Perhaps we are afraid the sun may shine in our eyes; or perhaps there is some other sight nearer at hand but to our right or left we prefer to gaze at. As free citizens we have our choice, and there is no subordinate air-plane agent who can compel us to look up. This exercise of choice or will makes the act a voluntary one, or a voluntary non-action. All versions are of that character. You are welcome to use a different term to describe it, if you choose. Free speech is voluntary also, and all speech is voluntary, if you accept the penalty for saying indiscreet things.

3. *DEXTRA-VERSION:*

   This is that voluntary muscular action that normally rotates both eyes equally in a rightward direction; or restrains the eyes from turning abnormally to the left.

4. *SINESTRA-VERSION:*

   This is that voluntary muscular action that normally rotates both eyes equally to the leftward; or that restrains them from turning abnormally rightward.

If you are seated in an amphitheatre with an air-plane overhead, but a pretty girl at either side of you, you may look up to the air-plane as much as you choose, but there is nothing to compel you to. You may find it quite as entertaining to exercise a "dextra-version"

or a "sinestra-version" instead. But the main thing is that you have your choice, only that you are responsible for it. It might be the part of discretion to look intently at the air-plane.

These versions have all been observed and charted, but the versions of the eyes around their optic axes, or on their anterio-posterior axes, have not been charted. The eyes are so much alike all the way around that it would be difficult to tell whether they stood normally erect or not. Their versions on these axes, if ever charted, will be as follows:

5. *RIGHT-TOR-VERSION:*

   That voluntary muscular action that normally rotates the two eyes equally in the direction that the hands of a clock move, or restrains them from the opposite turning.

6. *LEFT-TOR-VERSION:*

   That voluntary muscular action that normally rotates both eyes in the direction opposite to the hands of the clock, or restrains them from turning the other way.

Version Co-ordinates

It seems like a waste of time and space to point out what muscles are engaged in pairs to effect the above described versions, so we will be brief about it.

1. Hyper-version: Two superior recti active; two inferior recti serving to check the upward turning.
2. Hypo-version: Two inferior recti active; two superior recti serving to check the downward version.
3. Dextra-version: External of right eye, internal of left eye; with opposite pair checking movements.
4. Sinestra-version: External of left eye, internal of right eye; with opposite muscles serving as checks.
5. Right-tor-version: Inferior oblique of right eye, superior oblique of left eye; opposite pair checks.
6. Left-tor-version: Superior oblique of right, inferior oblique of left eye; opposite pair checks.

The above pairs of muscles are termed co-ordinates, as their rotations of the eyes are in the same direction and for the same purposes, to bring into the field of observation as wide a range as possi-

ble. The head and body movements are also co-ordinate to the versions.

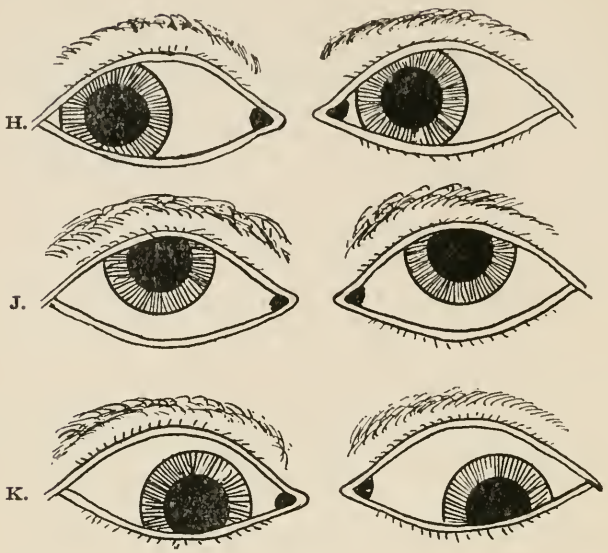


FIGURE 23.

Diagram of versions of the eyes: H, Right or dextra-version. K, Up or hyper-version. J, Combined leftward and downward version.

Version Characteristics

The versions of the eyes are the most natural of their movements or muscular tensions. If we had but one eye, we would still require to make the same movements to extend our field of visual observation. Binocularly we make these movements as naturally as we would with but one visual organ. But the eyes are not duplicates, for one of them is the right eye and the other is the left, and they differ the same as the right and left hands or feet. We refer however, to their differences in character from the ductions.

The eyes are a team, and like the movements of a team of horses, their versions correspond. The motor-nerve stimulus that comes to the muscles for the versions, or the neuro-motor center, is deep seated. In controlling the direction of a team of horses with the reins, a pull upon one rein turns both horses' heads together in the

same direction, and by one impulse. Our versions of the eyes are like that. To turn one eye is to turn both of them, and equally in the same direction. In the reins this is brought about by dividing each rein into two segments, one going to the right side of the bit in each horse's mouth and one to the left side of each. It is the segments of each of the reins that correspond to the eye muscles, but the control is in the one line or one impulse along it.

But version control of the eyes is much more complete. We turn the eyes in any direction, not merely in two opposite directions, and we are constantly exercising this control. The versions are the *primordial* rotations of the eyes. We cannot negotiate the version of one eye alone without the other "going along with it". Otherwise it is not a version. Cover one eye and change the direction of the object for the uncovered eye; and back of its cover the covered eye, which does not see the object, will rotate with the uncovered eye that does see it. There is *unison* of rotation of the two eyes. It is not impossible to break this unison of motion, for otherwise we could have no ductions, but the natural unison of the two *resists* or opposes their separation of movement.

The range of the versions is wide. Normally, for an object in a direction of 45° from the vertical medial plane to the right, a version of that amount may be exercised. Such a version is the equivalent of 100△, for it amounts to 100 cm. in a meter's distance. But leftward the eyes may be deviated an equal amount or 100△. This makes a total horizontal version of 200△, while maintaining binocular single vision. We prefer the terms "dextra" and "sinestra" version for these movements to the terms "ab" and "ad" version; for to the rightward it would be "abversion" of the right eye and "adversion" of the left eye. But there appears to be neither *ab* nor *ad* to a version, with the two eyes turning together in the same direction. Those prefixes are appropriate for the ductions only. Vertically there is about the same version power, but the amounts are unimportant, since they are entirely adequate. The tor-versions are more limited, as the oblique muscles function more importantly in steadying the eyes for all of the other versions and ductions than in making specific turnings of them axially.

Since the versions are primordial and natural, it follows that

even a blind man, with eyes, will rotate them in this manner; and the new born babe does not have to wait for hard experience to teach him the art, as he exercises it instinctively, and from birth, and quite as competently as a grown-up, provided the eyes are normally mounted and the muscles are normally attached so as to produce the condition known as orthophoria, or something not too far departed from it. Optically, normal version powers are expected of the eyes.

Version Test

The purpose in making a version test of the eyes, is to ascertain the range of their unison of rotation, indicating that both of the muscles of a version pair are functioning together. The test may be made in a simple way by holding a small target a few feet before the eyes, having the patient fix it, and, instructing him to hold the head stationary, move the target horizontally and vertically while observing the rotations of the eyes to follow it. The fact that he is converging to a near object will have but slight effect upon the amplitude of movement, and at the extreme points. If, in such a test, one of the eyes slows up or stops, the muscle that has ceased to function is located. It is the muscle that fails to rotate that eye in the direction of the target.

This test may be reduced to a visual one by using a small light as the target and covering one eye with a red disc. If he fixes the target the images will fuse as a combination of red and white, or appear as a single pink light. Then in moving the target as described, it should continue to appear as a single pink light. Separation of the two lights at any point indicates that one of the eyes is lagging behind the other or that it may have stopped altogether. The eye that lags or stops will see its target (red or white) move faster in the given direction, taking a position in advance of it. Therefore, at the point where diplopia appears, version of the eyes has ceased, for they are no longer rotating equally in the same direction. The non-functioning muscle lies on that side of the eye that lags, toward which movement is being made.

For example, if the red disc is before the right eye, and the distance of the target is one meter, and a rightward movement may be made of 50 cm. without diplopia, this is 50$\triangle$ of a version in that

direction. But if at 60 cm. to the right, the red light appears farther to the right than the white one, it is the right eye that is lagging behind the left, or has stopped altogether, and it is its external rectus that has ceased to function at the 50 cm. distance. If a leftward movement of the target produces a break to diplopia at 40 cm. and the red light again goes ahead of the white one, it is again the right eye that lags, and this shows that its internal rectus will not function beyond the point indicated, 40△ to the leftward. The eye that sees the target move the faster or the farther is the stationary or lagging eye.

It may be that there will be initial diplopia, or that a red and a white light will at once appear, and this indicates a muscular imbalance with which we are not at present concerned. It is only necessary then to observe the effects of the versions called for by the movements of the target upon the relative positions of the two lights. If version is normal in every direction, the two lights seen (red and white) will maintain their fixed relative places, showing that the versions are normal notwithstanding the initial diplopia. If the eyes have binocular single vision, initial diplopia because of one of the lights being given a different color than the other, is not usual, even if there is any muscular imbalance to account for it.

In the above version tests, which may be duplicated for vertical movements, the right eye will be able to maintain fixation of the target for a greater movement to the right, and the left eye for a greater movement to the left; but it is not necessary to carry the test to these extremes. If fusion is maintained for 50 cm. in a testing distance of one meter, it may be assumed that the horizontal versions are normal; and a range of 50 cm. up and 50 cm. down may be regarded as normal for the vertical. In a testing space of 1 meter, these centimeters reduce to prism diopters, which are represented by the sign, △.

Version Anomalies

The structure or attachment of the ocular muscles may be such as to give them an abnormal tendency to deviate from their primary positions, either up or down, to right or left, or torsionally. For versional directions of such tendencies, these would be called

The Homophorias

There are of course as many kinds as there are primary directions of deviation, and they are named accordingly. The term "phoria", wherever used in the nomenclature of the muscles, indicates a tendency of the eyes to abnormally deviate in some direction; but out of the miscellaneous collection of prefixes, hyper and hypo, super and supra and sub or infra, ana and kata, etc., we select what we consider to be the most appropriate ones only.

1. *HYPER-PHORIA:*

   A tendency of the eyes to deviate abnormally but equally upward, most usually designated "anaphoria".

2. *HYPO-PHORIA:*

   A tendency of the eyes to deviate abnormally but equally downward, sometimes called "kataphoria".

3. *DEXTRA-PHORIA:*

   A tendency of the eyes to deviate abnormally but equally to the right or rightward.

4. *SINESTRA-PHORIA:*

   A tendency of the eyes to deviate abnormally but equally to the left or leftward.

5. *RIGHT-TOR-PHORIA:*

   A tendency of the eyes to rotate axially in the direction of the clock hands, as seen by patient.

6. *LEFT-TOR-PHORIA:*

   A tendency of the eyes to rotate axially in the direction opposite to the clock hands.

As these are but tendencies, it is assumed that the ocular muscles interpose and prevent such abnormal rotations. This action engages the version pair of muscles that would normally rotate the eyes together in the opposite direction. Thus for the 1st, it is the inferior recti muscles that restrain the eyes from turning abnormally upward. This action would produce a constant strain upon these muscles. Therefore, to relieve the muscles, the head may be tilted forward, so as to allow the eyes to turn upward while looking horizon-

tally ahead. In the same or analogous manner, the 2d would cause a strain upon the superior recti and this is relieved by tilting the head backward. For the same reason, in dextra-phoria, the head is turned to the leftward, or in sinestra-phoria to the rightward.

As these abnormal tendencies or turnings do not impair fusion nor disturb binocular single vision or fixation, they are not given much attention. A version test would show that the eyes can be turned farther in the direction of the "phoria" than in the opposite direction; for the tendency is a help in the first direction, but a handicap in the second. There are occasional cases in which these "homophorias" or one of them may be very bothersome and distressing, and the "hyper" or "ana" phoria is the one most frequently found of that character. The only optical relief for it would be a pair of prisms, base down, over both eyes. It is usually complicated with other muscular anomalies, and any operation is likely to introduce this complication.

FIGURE 24.

Character sketches. Appearances of people with Homophorias of different varieties: H, Hyperphoria, head tipped forward. K, Hypo-phoria, head tipped back. J, Dextra-phoria, head turned to left.

Version Exercises

In making the version tests heretofore described we are exercising the muscles in version pairs. In our every day experiences, whether stationary or moving about, the eyes are constantly roving from point to point, and one might consider that this was exercise enough. But for the same reason that we have to be encouraged to

take due care of our health by muscular exercise, such as walking, riding, traveling, there is a possibility that, from want of sufficient exercise, or a too limited range of exercise, the ocular muscles fall into the same dormant state that the other muscles of the body are sure to acquire from the lack of sufficient physical exercise.

To encourage physical exercise we use dumbbells, trapezes, swings, spring boards or a whole gymnasium equipment and make periodical visits to it for that purpose. But such exercise is greatly stimulated by the presence of others who are taking the same measures as ourselves to develop their muscular powers. Swimming, skating, rowing, running, horse-back riding and other out-door exercises are indulged. Theodore Roosevelt would shoulder his axe, march into the forest and cut down and trim a big dead tree, for he loved trees too well to sacrifice live ones for that purpose. But our greatest means of stimulation is competitive games, such as base-ball, tennis, golf, foot-ball and kindred "sports" not to mention arduous hunting and fishing trips to the northern fastnesses, where we endure hunger and cold to accomplish our ends, and the primary purpose is nothing but "exercise".

Wherever we go and whatever we do, the ocular muscles are in a constant state of activity. But ordinarily the range of action is not as wide as necessary. Therefore it is well to devise a systematic course of exercise for the development of these muscles. The late Charles H. Taylor, of Yankton, S. D., although styled "Doctor Taylor", was not an M. D., at least in practice, but an optometrist. He devised a system of muscle exercise for the eyes, to which he gave the euphoneous name of

"Oculo-Didactics"

It is probable that this would have been better understood under a simpler title, but that point may be questioned. He was not satisfied to see a single pair of eyes exercising in unison, but wished to see dozens or hundreds of them working together, so that he had version of each of the pairs, as well as version of the hundreds of pairs together. For the purpose he introduced these exercises into schools, and hundreds of pupils, uniformed or in gym dress, would go through with the exercises together. It was an attractive sight, and he won the confidence and approval of school superintendents,

principals, teachers and "the kids" as well, wherever he gave them. Naturally this won their patronage also, and there are more people wearing Dr. Taylor's glasses in South Dakota than are wearing everybody else's put together.

The doctor also interested many optometrists in the exercises, especially in Oklahoma, where he traveled for a time, giving them instructions in the art of oculo-didactics. To make one prominent in practical optometry he must ride a hobby, and there is no objection to it, if the hobby is a good one. A good deal of the attractiveness in an attractive personality is featured most prominently in the eyes and their activities, and exercises of this kind add to their attraction. But Dr. Taylor was as "euphoneous" in his description of the benefits to be obtained from the exercises as in the title he gave them. Seeing a lady enter a store, a man walking along before him, or a school girl picking her way across a muddy street, he would see in their movements, the style of walk, signs of muscular "rigidity" to be overcome by oculo-didactics.

Character Studies

One should not be too hasty in forming his opinion of a person's character by the way he carries his head, or by some peculiarity in his way of looking at you. The 'phorias we have just described may account for some of them.

If your new acquaintance walks along the street with his head tilted up or back, it may be because he is vain or proud or thinks too much of himself, but it is possible that he has Hypophoria, or a tendency of the eyes to turn downward, due to some structural malattachment of the inferior recti too far forward on the eyes, or of the superior recti too far back, and that it causes a perpetual strain or tension on the superior recti to hold the eyes level in their orbits. By tilting the orbits upward, which he does by tilting the head back, he relieves this tension and strain, and may be quite unconceited and humble notwithstanding appearances being against him.

If you become acquainted with someone who looks at you from under his eyebrows, tilting his head forward for the purpose, you may regard his looks as furtive, and that he has some villainy in con-

templation, or that he meditates attacking you forthwith. But it may be that he is afflicted with a Hyperphoria, or a tendency of the eyes to turn abnormally upward in their orbits. Therefore, he tilts the head forward to allow his eyes to assume a pose that is restful to the muscles that otherwise would be overtaxed to hold the eye down to the level position. Your life and your pocketbook may be perfectly safe from violence as amiability and good fellowship may be his real characteristics. Give him at least the benefit of the doubt.

You may meet a man or a woman who casts "goo goo" eyes at you, turning the face to right or left away from you, although looking into your eyes as straight as anybody. Don't conclude that, if it is a man, he is avoiding your eagle eye, fearing it will penetrate his character; or, if it is a woman, she is trying to get up a flirtation with you at the first meeting. People who carry the head habitually in this manner and appear to be averting your penetrating scrutiny, are only trying to get a little relief from the tension on a pair of muscles by turning the orbits to such position that the muscles are relieved of the task of holding the eyes in their primary position. Dextraphoria or Synestra-phoria may account for the whole matter.

You will meet some people who tilt their heads sideways, the forehead to the right and the chin to the left. In that way they relieve the oblique muscles of an abnormal strain, or perhaps they have oblique astigmatism and can see better when the head is tilted one way or the other. It may indicate a "coy" disposition, bashfulness, embarrassment, but you had better consult their other features, their language and especially their actions, rather than pin your faith to appearances only. Dr. Taylor might explain these postures on the theory of an abnormal rigidity of some of the ocular muscles, but without such rigidity of the head and neck muscles the strain would come on the ocular muscles which are less able to bear it.

Character reading from external signs and symptoms is immensely enhanced by studies of the eyes; but no external signs are really infallible. The eyes contribute a very important element to the study, but such signs may be taken as initial merely, something to be later explained by any of the muscular abnormalities included in the Homophorias, as well as by other signs not yet considered. There

is little the optometrist can do for these muscular anomalies, except along the lines of exercise, or by Oculo-Didactics, as Dr. Taylor has christened them.

CHAPTER VII

Duction of Eyes

The term "duction" as applied to the eyes has already been defined as "that involuntary muscular action that normally rotates the two eyes equally in opposite directions". It is the muscular function that controls the *relative* positions or directions of the visual axes, and is essential to the binocular fixation of objects at different distances from the eyes, near and far, and without regard to their direction from the eyes.

In binocular fixation, which is essential to the fusion of the images and single vision, the two visual axes must meet at the objective point of fixation, whether far or near. Light from it will then be focused at the center of the fovea centralis of each eye, which are the subjective points of fixation. As the eyes are separated by the space between their rotary centers, to fix a near object they must be relatively in a slightly different position, turned inward, in which the right eye is turned to the left and the left eye is turned to the right. In changing this relative position for the fixation of a more distant point, the right eye must be turned to the right and the left eye to the left. These are duction movements of the eyes. They are the only normal ductions.

But on account of the obliquity of the direction of the object, one eye may be required to rotate less than the other, or even one may be required to remain stationary or fixed while the other eye executes the entire rotation. This is a combined version and duction, and the two functions, when exercised together, must not be confused with one another. Version takes care of the obliquity of the direction of the object fixed, duction with its nearness to the eyes. In the instance referred to above, when one eye remains stationary, both duction and version are participated in by both eyes, but for the single stationary eye the two neutralize each other.

Contest of Functions

In the execution of a duction of any variety inward, outward, upward or downward, the functions of version and duction are in conflict. The rotations of the two eyes are naturally and primordially in the same direction, and the movement is voluntary. But, in

a duction movement, this rule of co-ordination must be violated. It is a *conjugate,* rather than a co-ordinate movement. As we accommodate to conjugate an objective point focally with the retina, we execute a duction to conjugate the two retinal images of a single object or place them in the relative positions for fusion. Hence the muscles that execute a duction must overcome the version tendencies of the eyes to rotate in the same direction as well as to rotate them in opposite directions.

It is on this account that duction movements of the eyes are so much more limited in scope than the versions. While we may easily execute a version to the right or left of 100△ or more, we cannot usually rotate the two eyes inward more than 25△, unless by exercise we develop greater duction power in that direction. But in an outward direction, the effectiveness of a duction in rotating the eyes is very much more limited, since about 8△ is the limit of such duction movements. In a vertical direction, the duction movements are still more limited, for turning the right eye higher than the left or the left higher than the right is often limited to 2△, and is seldom above 5△. The capacity of the muscles to execute rotations is very much greater than this, as shown by their versions, but for executing the ductions the version pairs of muscles are perpetually resisting duction.

It must not, therefore, be thought that, because a particular duction is weak or ineffective, the muscles that execute it are weak. The duction pair of muscles has not been taught, as they must be by experience, to rotate the eyes in that unusual manner; nor have the version pairs that offer a natural resistance to such movements been taught to be submissive to them. A farmer who drives to the city often will get his team quickly out of the path of a fire engine; but one who seldom goes to the city and is unused to its ways, will not be so quick to take the alarm or move his rig out of the path of the fire-fighters. The muscles fall into these special habits only when taught by experience that worse consequences follow their negligence or omission.

Normal Ductions

When the eyes are normal and in normal muscular balance, viewing a distant object, such as a sail upon the horizon, or search-

ing it for one, calls for no duction of the eyes, and the visual axes are parallel while the versions are taking place. If a sail is discovered, it is binocularly fixed by the paralleling of the visual axes. But as it approaches the observer or he approaches it, a slight degree of convergence begins to be exercised, and convergence increases gradually with its approach. The visual angle is also increasing, and accommodation begins to be exercised. But all of these, for a distance such as this, are very slight.

If, when within a quarter of a mile of the observer, the boat is turned and sails away, the eyes are diverged, the accommodation is relaxed, and the visual angle of the boat diminishes with its distance. The convergence of the eyes for its approach or nearness is an exercise of *adduction*. The divergence of the eyes with the recession of the object is an exercise of *abduction*. To fix the object at any distance the two functions must be balanced for that distance. They oppose each other, and are both opposed by the versions. For an object at 20 ft. or 6 meters, it is not considered that any convergence is necessary, although as it is about 6 centimeters for a distance of 6 meters, it is 1 cm. to the meter, or 1△.

The muscles most primarily involved in exercising adduction are the internal recti muscles, with the externals acting to check excessive convergence. For abduction the external recti are primarily active, the internals acting merely to check over divergence. The guiding sensation that determines the relative action of these opposing muscles is the fusion of the images, or single vision of the object. But for objects at such a distance as the above, both adduction and abduction are of inappreciable amounts or values. They are supposed to begin only when the object fixed is nearer than 20 ft., unless there is an imbalance of the muscles that makes duction necessary for infinity.

The Meter Angle

When the object is at a distance of but 1 meter from the eyes, normal adduction for it is the 6 cm. for the distance of 1 meter, or 6△. But to provide a designation that corresponds to the 1 D. of accommodation that is required by each eye for an object at that distance, this degree of convergence or adduction is called 1 meter-angle. The meter-angle is the angle formed by the meeting of the

visual axes at a point of fixation that is at a distance of 1 meter from the eyes, or at an object that is at that distance. If the objective point of fixation is in an oblique direction from the eyes, that is not regarded as changing the value of the meter angle, nor in lessening

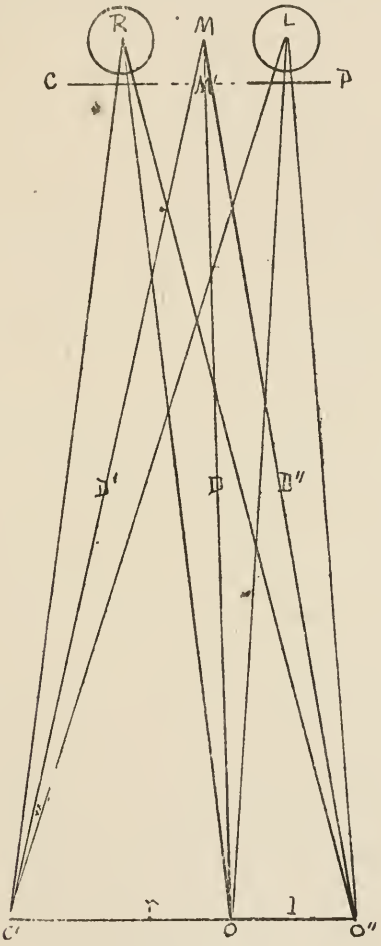


FIGURE 26.

Binocular fixation of points O, O′ or O″. R, right eye, L, left eye; M, midway point between centers of rotation; CP, correction plane; M′, midway point in CP; D, D′ and D″, binocular direction of O, O′ and O″. Lines converging from R and L to O, O′ or O″ are visual axes from centers of rotation to those objective points of fixation. The r and l represent primary direction of visual axes from M or M′.

the equal participation of the two eyes in it. As stated heretofore, the versions take care of the obliquity of direction of the object point fixed, the ductions of its distance from the eyes.

On account of the variations of different people in the matter of width between the eyes, the meter-angle is of indefinite angular value, measured in degrees, being greatest for those whose eyes are most widely separated. But since, whatever that distance, accommodation of 1 D. for the distance of 1 meter co-ordinates with convergence of 1 meter-angle for the same distance, the space between the eyes is not regarded as affecting the meter-angle in an optical sense. The fixed average distance of 6 cm. provides the basis for reducing a meter-angle to its equivalent in prism-diopters, and vice-versa; and whether the reduction, one way or the other, is a little above or below this average is regarded as a negligible question. In reducing meter-angles to prism-diopters we may allow for an unusually wide or narrow space between the eyes.

In the 1 meter-angle of convergence for an object point at that distance, a line connecting the rotary centers of the eyes makes the 3d side of a triangle, in which the visual axes are the lateral sides. If a line is drawn from the point of fixation to the center point of the base of the triangle, it will bisect the meter-angle or divide it into two equal segments. The line itself is the binocular direction of the point of fixation or object point. Whether it is perpendicular to the base line, or oblique to it, the angles at each side of it are equal, and each represents the angular excursion that either eye must make from parallelism to the fixation point. Their excursions from the primary positions are of course unequal, except for a point in the medial vertical plane, but inequality of excursion does not alter equality of adduction or abducton, or of convergence or divergence.

If the point of fixation is in a plane 1 meter forward of the eyes but 20 cm. to the leftward of the vertical medial plane, a fixed normal leftward version of the eyes is required for its binocular direction, and a fixed normal convergence is required for its distance, or the distance of the plane from the eyes. The version is leftward (sinestra-version) 20△ for the object point of 20 cm. in a meter's distance from the medial plane, although the left eye rotates but 17 cm. leftward and right eye 23 cm. in the same direction. The

difference between the two is the amount of the adduction, which is 6△. If the left eye is fixing a point directly before it, and the right eye makes the entire excursion of 6 cm. (which is a fanciful supposition) still the two eyes participate equally in the adduction; for in order to converge the eyes to such point, the left eye must remain stationary or fixed and repress its natural tendency to turn leftward with the right eye.

The Object Distance

In establishing the meter-angle we place the objective point of fixation at a distance of 1 meter from the eyes, but from what point, or datum? To be mathematical about it, it would have to be 1 meter from the respective centers of rotation, or from the base of the triangle we have referred to, the line connecting the rotary centers, or from its center. But this is an inaccessible point and therefore impracticable. An interpupillary line, or its center, would not be much better. Considered from a practical, rather than a mathematical standpoint, distances in front of the eyes should be measured from the *correction plane* of the eyes, the position in which lenses for the correction of the eyes must stand or be placed to neutralize distance or measure optical defects of the eyes, as well as to correct them. This position is at about 14 mm. from the eyes, or forward of the corneas. It is therefore 14 + 12 = 26 mm. or 2.6 cm. forward of the line connecting the rotary centers, and 14 + 3½ = 17½ mm. forward of the interpupillary line, or its center.

Since this plane, rather than the plane of the rotary centers, is the actual datum for neutralizing distances or making optical corrections of the eyes, whether it suits us mathematically or not, and is the approximate location of the anterior principal foci of a pair of normal eyes at which lenses of any value do not alter the combined focal-length of the eye and lens, we might as well accept it and measure distances forward of the eyes from it. It will not materially alter the equivalency of it to 1 D. or to 1△ to it posteriorally, and is the exact equivalent of 1 meter anterior to it. It places the object at 1 meter 102.6 cm. forward of the rotary centers, instead of 100 cm., and this is as close a position as we are able usually to get. For nearer distances than 1 meter, the same 2.6 cm. must be added, which is relatively greater for them than for 1 meter. But

as our prisms for measuring the ductions are necessarily placed in that position we are making it the actual point or plane from which to measure distances whether we are pleased with it or not.

Convergence vs. Adduction

The two above terms, as well as divergence and abduction, are used interchangeably in the preceding pages, or as synonyms. They are not really synonymous, however, nor equivalents except in orthophoric eyes. The term "convergence" is a physical term. It expresses the relative positions or directions of two lines that meet at a point, and is applied to any two lines in that relationship. There is no suggestion in it of an action, muscular or otherwise. On the other hand, the term "adduction" is a physiological term. It indicates in the eyes a muscular action that normally converges the visual axes, or that lessens or neutralizes their divergence. If the visual axes are parallel, they cannot be said to be convergent; but a considerable adduction may have been necessary to parallel them, and must be continued to preserve their parallelism. Convergence is the static, adduction is the dynamic term. Divergence and abduction have the same relationship.

Since we have defined the term "duction" as a muscular action, rotation of the eyes is not material to the exercise of it; and both adduction and abduction, or any duction of the eyes, are merely ductions qualified as to their direction of action. In practical optometry we have a great deal to do with ductions that do not rotate the eyes, and very much less to do with the ductions that do rotate them. It is this fact that makes it important to define the term as we have. There are other qualifying words in the definition that will be considered later. From the definition it may be seen that the rotations of the eyes may even be contrary to their ductions. But nevertheless all movements of the eyes horizontally are due either to ductions or versions. A pair of eyes, when fixed upon a point, are balanced in abduction and adduction, for otherwise they would not remain in that relative position. But they may not be normally so balanced.

In the exercise of adduction, abduction is the function that acts as a check upon over-convergence of the eyes. In exercising abduction, adduction is the check. And these "checks" that are put upon

either are ductions also, for they are "that involuntary muscular action that normally rotates the two eyes equally in opposite directions", the same as the ductions that are effective in rotating the eyes in opposite directions. We lose sight of them because they do not initiate the action, or because their action is merely negative in effect.

Normal Near Vision

An object is not counted "near" unless it is within reach of the hands, so as to be adjusted to different positions. It is that distance at which we normally may engage both eyes and hands, as required in the various occupations. Among these are reading and the trades for men, or reading and sewing for women. As reading is one of the most important near vision occupations, that is the usual gauge for near distance. The most commonly accepted reading distance is at ⅓ meter, 33⅓ cm. or practically at 13 inches from the eyes. If we add the 14 mm. for the position of the correction plane in front of the eyes, it makes this distance about 14 inches, or 35 cm.

Some occupations and some eyes may require a greater or less distance, and the preferred reading distance is modified to some extent by the length of the arms. Hence, 14″ or 35 cm. from the eyes place the object at about ⅓ meter from the lenses that are used to neutralize that distance, or normal accommodation for it is 3 D. For this distance, normal convergence is the reciprocal of ⅓, or 3 meter-angles. Reduced to prism-diopters, it is 18△. This is the normal amount of adduction exercised for the distance. A plane at right angles to the vertical medial plane at that position embraces all points of fixation for normal reading or near vision. But in reading a book at that distance, as we visually pass over the successive lines, it is by the exercise of the version functions that we direct attention to different parts of the page.

Printed books are typed in such manner as to provide us, at that distance, with an angle of vision sufficient to make the images of the printed words of sufficient size to be plainly seen. If the type is of larger size it is seen easily at a greater distance, requiring less accommodation and less convergence; and if it is of a smaller size, it may be brought nearer, provided our accommodation is able to take care of it at such nearer distance and convergence may also be increased in the same degree. In a faint light, however, we usually

hold our reading at a nearer distance. This increases the volume of light from every point of the printed page to the eye, but it also exacts increased accommodation and convergence or adduction.

In the hundreds and hundreds of occupations and the thousands upon thousands of men and women, boys and girls that are engaged in them the exercise of these muscular functions of the eyes goes on perpetually. The versions and ductions co-operate; the ductions conjugate the same as the accommodation, and both co-ordinate with each other; and all of them co-ordinate with the manual requirements of the occupations. These include the stenographer, the store clerk, the mechanic, the factory hand, the shoe-maker or cobbler, the candy-maker, the doctor, the dentist, the optometrist or optician, the ticket-seller, the bank-teller and money changers generally, the teacher and the preacher. But more than any other class, the students at college and the pupils in the schools, what a vastness there is to it all; and most of this occupational work is done when the other bodily muscles are at rest and inactive. But the work of the ocular muscles does not cease with the ringing of a time bell, nor when the tired worker hangs to a strap in the street car on his way home, or even when he arrives at that destination.

A handicap to the exercise of these muscular functions of the eyes, due to some optical defect that lenses will eliminate and correct, is too serious a matter not to be given prompt and efficient attention, and this is the service to humanity that the optometrist renders. To be able to do so efficiently is not beneath the dignified ambition of the very highest human qualities and character. Let the optometrist therefore, regard his profession in that light, and make himself worthy of it.

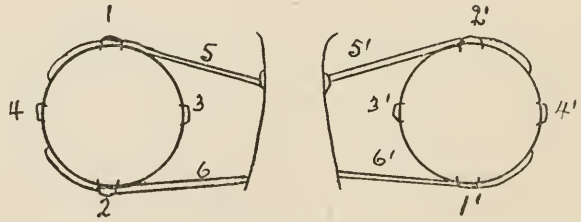


FIGURE 27.

Duction pairs of muscles: 1 and 1', hyperpo- or sur-sum-duction; 2 and 2', hypoper- or sum-sur-duction; 3 and 3', adduction; 4 and 4', abduction; 5 and 5', supracyclo-duction; 6 and 6', infracyclo-duction.

Fixation of Object

In "searching" the objective field for an object either near or far, the visual axes are adapted, in relative positions or directions, to the direction of the object as well as to its distance. Thus, in viewing the distant horizon for a sail, the visual axes are directed, not to one point of it, but sweep it from point to point. The object is most likely to be perceived, at first, by indirect vision, but immediately we catch sight of it in that way, direct vision is turned to it, so that its images may fall upon the subjective points of fixation in both eyes at once. The eyes will turn in that direction first, and by a version movement. We may then turn the head so as to face it and see it squarely.

A sail upon the horizon that has to be searched for in that manner will make but a small image upon either retina, perhaps the 5′ angle of vision whose tangent is .00145. The images will therefore occupy but a small portion of the fovea centralis of either eye, whose visual angle is about 68′, and whose tangent value is practically .02. By comparison either of the angles or their tangents, it is about 1/13 of the diameter of the fovea, or 1/170 of its area. It is not surprising that fixation of so small a target and the maintenance of fixation upon it is rather tiring to the muscles that are engaged. With the approach of the object it becomes easier for we are not apt to lose sight of it merely because vision wanders to different points of it. The fixation distance changes but slowly, for convergence is but slightly changed in the approach of a boat from 5 miles to one-half of a mile.

In the same manner we search for a near point of fixation, such as a particular word or letter on a page of reading matter, a dropped coin on the ground, a particular character in a drawing, a special item in a column of "want ads" and so on down to the proverbial "needle in a haystack". If we know exactly what we are looking for we may see it more quickly than if it is an unknown article. But in such a search and the final discovery of what we are searching for and its binocular fixation the duction and version functions are in constant activity. When, as in an hour's reading, the characters we are fixing are constantly changing and must be clearly visualized as

the images "flow" across the retinas it is surprising that we are able to keep it up hour after hour with unabated intensity and interest.

To wish to explore the visual organs for the purpose of locating the agencies for exercising the functions referred to and finding more details in regard to them, is like asking the captain of the steamer that has carried us to distant lands for a permit to explore the interior of the ship. It has taken us, in luxury, across wide oceans, brought us to distant cities, given us a view of the magnitude of the world and displayed its wonders, but we still wish to inspect its engines, cargo, and interior parts, including the culinary provisions by which we have been fed, the cabins, sleeping quarters, kitchen, and the ship's force of men and women who have kept things going, its instruments for navigation, its wireless communication with the other parts of the world and even the coal supply, the stokers, the engineers and everything about it. Complete and competent as all these are they are not so wonderful as the visual apparatus by which we see, nor nearly so automatically operated.

We must know these details in order to know what artificial means to employ to overcome any weakness of functioning, by which these high but delicate duties are exercised, and to supply them with the best artificial agents for correcting their defects, so as to give the natural or normal functions the best opportunities possible for the discharge of those functions easily and comfortably, for this is essential to the full enjoyment of the highest of all human senses—vision.

Duction Muscles

In the exercise of the ductions we have the same orbits for the eyes to rotate in, the same eyes to be rotated in them, the same complete set of extrinsic muscles to operate them, and the same system of motor nerves to stimulate their action as in the versions. But the muscles are binocularly associated in different pairs than for the versions, and their nerve stimulation is involuntary, or by reflex action from ganglionic nerve-centers. The purpose of such action (the ductions) is to obtain or to retain fusion of the images, or to so hold or rotate the eyes that the retinas will stand in their proper relative positions to receive the images on corresponding areas, as required for fusion.

In classifying the ductions and the muscles that execute them, the two will be considered together; and it will be necessary to introduce certain new terms, for nothing less than a surgical operation will suffice to correct some of the faults of the old ones. This applies equally to the 'phorias that make abnormal ductions of the eyes necessary. According to their directions of tension or rotation of the eyes upon their three primary axes of rotation, the ductions are as follows:

1. *Hyperpo-duction,* superior rectus of right eye with inferior rectus of left eye.
2. *Hypoper-duction,* inferior rectus of right eye with superior rectus of left eye.
3. *Adduction,* internal rectus of right eye with internal rectus of left eye.
4. *Abduction,* external rectus of right eye with external rectus of left eye.
5. *Supracyclo-duction,* superior oblique of right eye with superior oblique of left eye.
6. *Infracyclo-duction,* inferior oblique of right eye with inferior oblique of left eye.

As for the first term, the term "sursum-duction" may be substituted if preferred; and for the second, the term "sumsur-duction" as the accepted term should clearly indicate the fact that two duction muscles are the active agents, as a duction cannot be performed by one muscle. For example, when with a pair of orthophoric eyes, a prism is placed, base down, before the right eye, it is obvious that to maintain fixation of the object, the right eye must be rotated upward. But, it is equally obvious that the left eye must be held in its fixed position, or restrained from rotating upward with the right eye, according to its version tendencies. This puts the muscular tension equally on the superior rectus of the right eye and inferior rectus of the left eye. If it is not equal, the head will be tilted to make it so.

The adductions and abductions are normal only to the extent that it is necessary to engage them for the actual nearness of the object, adduction for a nearer object, abduction for a more distant

one. Vertically, the ductions are not called into action for the nearness of the object, nor for its lateral position. Such positions of it engage the muscles in version pairs only. The eyes are synchronous in vertical movements, and also for lateral ones excepting for nearness. The cyclo-ductions are employed essentially as supplementary to horizontal or vertical ductions and versions, to prevent the eyes in these movements from getting out of binocular alignment. There are cases in which a cyclo-duction is necessary for fusion of the images. But our data on that subject is very limited and confined mostly to those of oblique astigmatism as an initial cause.

In executing a duction of any variety, it is obvious that both of the muscles of the duction pair for that direction are equally engaged; for if they were not, and one of the muscles exercised a stronger traction than its duction mate, the eyes would not be balanced in that relative position. The eye upon which the stronger traction was spent would turn toward the muscle exercising it, and the other eye would have to follow it to preserve fixation, so that this action would balance the two, making tension on each the same or converting the movement into a version. The idea of one muscle exercising greater duction than the other comes from confusing the two functions, ductions and versions. One of a pair of duction muscles may be acting more strongly than its duction associate, but in that case, a simultaneous version or a muscular imbalance explains it. It is not a duction excess of one muscle above the other.

Suppose a pair of orthophoric eyes are fixing an object in a direction that, at one meter from the eyes is 10 cm. to the right of the vertical medial plane. Then the right eye will have to be rotated but 7 cm. rightward from its primary position, while the left eye must be rotated 13 cm. rightward. As we have said before, this is a "fanciful" supposition, for what the respective eyes rotate to fix a given object depends upon their position at starting. If the two eyes had been fixing an object in the vertical medial (orbital) plane, at 1 meter distance, to change from that position to a point 10 cm. rightward, both would turn 10 cm. to the rightward or execute a version of 10△. The adduction of the two, except for the slight amount due to obliquity, would be continued as it was for the point in the medial plane. On the other hand, if the object were at infinity in the same

oblique direction, the visual axes would be parallel in that oblique direction. Bringing the object up to the meter distance would merely cause adduction of the 6△ required for that distance. Hence, both the version and the duction, considered separately, engage the muscles equally.

Nerve Control

The ductions are all involuntary, or controlled by reflex action. In the same sense as it used to be said, in explaining the pressure of fluids, that "nature abhors a vacuum", it may be said, in this connection, that "the visual sense abhors diplopia". Hence, the various ductions of the eyes are supplied as the "guardian angels" to protect the visual sense from experiencing this horror, and are automatic in their operation for that purpose. But a reflex action is exercised through a reflex arch, which includes sensory nerves to convey sensory messages, a ganglionic center, having gray matter in it, to receive and interpret the sensory messages, and nervous cells to generate and transmit motor impulse to the muscles required to act to relieve the sensory complaint. While under the supervision of the general nervous system, locally or within its range, it has complete control.

There must then be a nerve center for the stimulation of each of the varieties of duction, or directions in which a duction pair of muscles act. The 3d nerve ganglionic center has been located, but this center, if it generates all 3d nerve stimulations, is given the discretion of a small brain, and perhaps that is the true function of the ganglionic nerve centers. They are little brains, set apart for a specific function. This is very simple when applied to accommodation and adduction, for both are stimulated directly by the 3d nerves. It is not so simple when abduction is to be accounted for, for here the 6th are the motor nerves and they must have a different motor-nerve center. With respect to the vertical ductions, the case is even more complex, for sur-sum-duction requires stimulation of the superior rectus of the right eye with the inferior rectus of the left eye; and sum-sur-duction engages the opposite duction pair; while each pair acts as a check upon the other pair, thus engaging all four of the muscles, either to effect or check the rotation, for all vertical duc-

tions. As all four of these muscles are stimulated by the same 3d pair of nerves, it is difficult to see, unless there is a subordinate nerve center for each, how these ductions can be effected by reflex action.

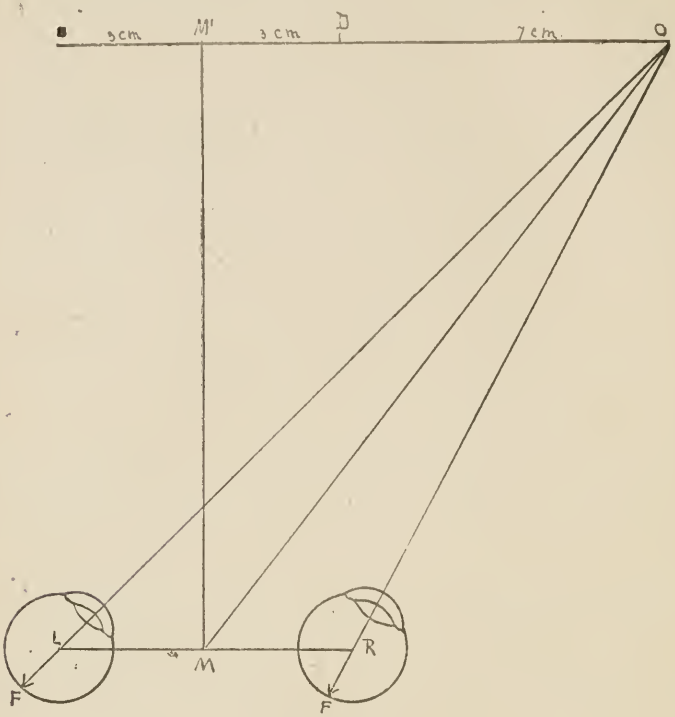


FIGURE 28.

Binocular fixation of O, in plane of DO, 1 meter from the eyes, but 10 cm. to right of M'; MM' medial orbital plane; MO binocular direction of O. Rightward version of eyes, 10△; Convergence of eyes, 6△; FO Visual Axis of right eye; F'O Visual Axis of left eye. Rotation of right eye, 7△ from D, but 10△ from M'; Rotation of left eye, 13△ from S, but 10△ from M'.

However that is not a question for the optometrist as much as it is for the physiologist, who has the laboratory facilities to investigate it.

But there can be no doubt these ductions are exercised, and by reflex action, for they are involuntary. A weak prism before either eye, base down or base up, will actively engage a duction pair, and passively or as checks, the opposite pair. Otherwise there would be

diplopia at once when the prism is placed as above. A stronger prism will produce the diplopia that the weaker one will not, showing that the muscles are able to neutralize the misplacement of the images unless it is of such an amount that the muscles are unable to neutralize the misplacement. The cyclo-ductions are also opponents, and a nerve center to stimulate each pair is essential to their involuntary action. There must therefore be six neuro-motor centers for the six different directions of the ductions to account for all of them, unless one grand nerve-center is made responsible for all the ductions. Let our brother physiologists wrestle with this question.

Duction Tests

Duction tests are made for the purpose of ascertaining the range of duction power a pair of duction muscles has, measuring in meter-angles or prism-diopters. Of the different ductions, that of adduction is naturally the greatest, for it is naturally exercised for near vision, and because the function of accommodation co-ordinates with it in near vision. But, in stimulating adduction for distance by placing a prism, base out, before either eye, the accommodation is not called into action by the nearness of the object, but must function by itself. Although the accommodation and adduction, acting together, may have a near point that calls for 8 D. of accommodation and 8-meter-angles of convergence, which convergence requires 48△ of adduction, in a distance test the adductors would be unable to overcome so much, or fuse the images, nor could the accommodation act so strongly but for the co-ordination of adduction.

When a near target is moved to a greater distance from the eyes, the convergence that was exercised for its nearness must be abated or reduced. The mere relaxation of the adductors is not sufficient to account for the outward movement the eyes must make. Here the muscles to check over-convergence, primarily the external recti, must contract to bring the visual axes more nearly to the parallel positions, and this is abduction. At the same time the accommodation must be reduced for a greater distance of the object, and this function is exercised by the fan fibers of the ciliary muscles. There is therefore co-ordination of this ciliary function with abduction, unless the test of abduction is made for a distant target by the use of a prism, base

in, before either eye or both eyes. To avoid the co-ordination of functions, a duction test of the horizontal muscles is best made with a distant target, and with prisms. Even then optical defects of the eyes that abnormally incite accommodation for distance, or put no demand upon it for near vision, must be taken into account. In fact, in the horizontal meridian, accommodation and convergence are so inter-related that the refraction must first be corrected before any clear idea of the ductions in that meridian of the eyes can be obtained with certainty.

Having eliminated the accommodative factor (1) by employing a distant target, and (2) by correcting the refraction, so that a hyperope will not accommodate for distance and a myope can see it, we determine the highest prism power the different duction pairs of muscles are able to overcome by proceeding to the point that causes diplopia. The highest prism power that the muscles are able to overcome, or in spite of which they fuse the images, that is the measure of the duction power in that direction, or with that pair of duction muscles.

In the vertical meridian, a prism base down before the right eye, or base up before the left eye, tests the duction power of the superior rectus of the right with the inferior rectus of the left eye, which is hyperpo- or sursum-duction. If these muscles fuse the images and we see but one when a 2° prism is so placed, but diplopia is caused by a 3° prism in the same position, their duction power is between 2° and 3°. To test the opposite pair, which is hypoper- or sumsur-duction, the prism must be placed base down before the left eye or base up before the right eye. Unless there is a vertical imbalance, favoring one duction pair and handicapping the other, the duction powers should be equal. But if there is 4° of hyperpo-duction and but 2° of hypoper-duction, an imbalance favors the former 1° and handicaps the latter 1°, making 2° for both. They are expected to be equal, for there is no natural reason for one being developed more than the other.

In the horizontal meridian, adduction is tested by prisms base out before either or both eyes. Usually the duction power in this direction, exercised by the internal recti muscles, will be upwards of 20° or more, as this is a much used function and developed more

highly than any other. It is not the special strength of these muscles that give them this greater duction power, for a duction test is not a test of the muscular strength of a pair of muscles, but their ability to overcome the version tendencies. When the right eye is turned leftward or inward, there is a natural tendency of the left eye to turn in the same direction; and not only must this tendency be overcome, but the eye actually rotated in an opposite direction. Hence, even adduction is limited in range by this "conflict of the functions."

Abduction is tested by prisms base in, on the distant target. The prism may be placed over one eye only or over both eyes, their bases being of course in opposite directions. The duction pair of muscles in this case, are the external recti. In the versions each has a rotary power of about 100△, but when used together as a duction pair they seldom exceed 8△, or, as we express it usually, 8°. Nor is this limited duction power to be interpreted as "weakness" of these muscles. They have an ample strength for rotating the eyes, but in the ductions they are in conflict with the version tendencies, and have to appease that tendency before they can rotate the eyes at all in this manner. The only natural exercise these muscles have is in turning convergence of the visual axes back to parallelism.

If the target is at 20 ft. it should be of sufficient size and distinctness to be plainly visualized by both eyes at that distance. A white character on a dull black background, such as a square white card 2″ by 2″ is suitable, as double vision of it would be distinctly marked. By the use of a red disc before one eye, this would show, when the prism caused diplopia, which eye saw the different targets, white and red, and the kind of diplopia. More elaborate arrangements may be provided, according to the ingenuity of the user. The prisms from the trial case answer all purposes, although the use of a phorometer, except that it limits the prism powers that may be employed may be used if preferred. There must be means of making the patient understand what the tests mean, if his or her co-operation with you is to be obtained.

Duction tests of the oblique muscles, acting independently, may be made with a pair of cylindrical lenses of weak power. If the eyes are both emmetropic, the astigmatic chart at 20 ft. appears of even color and distinctness throughout. Hence a pair of weak plus cyl-

inders, + .50 cyls. ax. 180, will blur the horizontal lines, leaving the verticals alone distinct. Rotation of the cylinders in the same direction causes the oblique muscles to work in version pairs, to preserve the clear vertical lines erect. This is co-ordination of the oblique muscles. But if they are rotated in opposite directions, the oblique

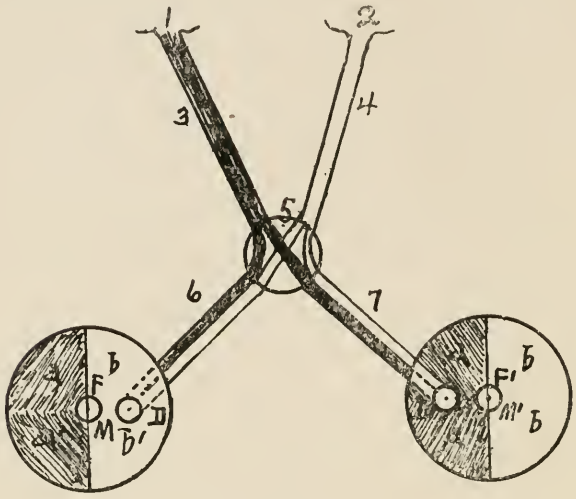


FIGURE 29.

Representing corresponding areas of retinae, with their nervous connection with brain. 1 and 2, right and left brains; 3 and 4, right and left optic tracts; 5, chiasm; 6 and 7, right and left optic nerves; D and D', right and left optic discs; M and M', right and left maculae; F and F', right and left foveae; a and a, a' and a', b and b, b' and b', corresponding quadrants of retinae.

muscles will be stimulated in duction pairs to preserve fusion of the clear lines, or prevent them from assuming a slant or cross position. This is conjugation of the obliques. But there is little actual rotation of the eyes on this axis, as a slight rotation tends to double or cross the clear lines.

The normal duction powers of the several pairs of duction muscles are about as follows:

1. Hyperpo- or sursum-duction, 2° to 5° or △'s.
2. Hypoper- or sumsur-duction, 2° to 5° or △'s.
3. Adduction, without training, 20 to 24 △'s.

4. Abduction, without training, 5 to 8 △'s.
5. Cyclo-ductions, rotation of 2° to 5° of .50 cyls.

The normal ratio of adduction to abduction is about 3 to 1, for the adductors are in constant use to rotate the eyes to convergence for near vision, while the abductors are only normally employed in the negative capacity of bringing the converged visual axes back to parallel positions. If the abduction is ever found equal to adduction, it indicates an imbalance favorable to the abductors and handicapping the adductors to the same extent. But counting the imbalance against the pair favored by it, and with the pair handicapped, the ratio is then about as 3 to 1.

It is seen therefore that "imbalances" of the duction pairs of muscles may give a pair the appearance of greater power than belongs to them, and the opposite pair an appearance of weakness that does not pertain to them. We therefore have this as a new factor to deal with, to discount the apparent superiority of one duction pair over another and to add to the power of the apparently weak pair. As this factor enters the field in all duction tests it must be taken into account, which leads to the discussion of the muscular imbalances, or heterophoria.

Reflex Influences

As the ductions are involuntary, or operated by reflex action, the sensory warning that the images tend to separate, producing diplopia, is conveyed over sensory nerves to the ganglionic nerve-center having control over the muscles that maintain fixation; the message or warning is received and interpreted by the ganglionic nerve-center: the generation of motor stimulus at that center, and its direction and transmission to the appropriate muscle or muscles follows; and the response of the muscles to the stimulus, and thus keeping the eyes and vision out of trouble, give the reflex arches having control over the different activities plenty to do. Like the telephone wires, the sensory and motor nerves are always "humming" with messages, or in a perpetual state of excitation and action, even while one is enjoying the quiet pastime of a stroll down the street, in the park, or over a country road. For the scene is constantly shifting and the point of fixation is constantly changing, keeping both the versions

and the ductions perpetually in a state of activity. And yet so perfect are the physiological provisions for these sensory and motor nerve activities, and for their control of the ocular muscles, that all of these functions operate without even diverting our attention from "what" we see, instead of engaging it upon "how" we see it. We do not have to think about what our eyes or their muscles and nerves are doing.

While sauntering along we give ourselves up to dreams of other things, perhaps far from our immediate environment, trusting to the spontaneity of these reflexes to take in all the sights on the way and to be attracted by anything unusual or out of the ordinary. For the eyes alone and their activities, six of the twelve pairs of cranial nerves are directly employed, and we must control the pupil and regulate the accommodation by the same means. The exercise of the versions and ductions are an important part of it all, but not the whole of it. The other six pairs of cranial nerves are not, in the meantime, idle. We may be engaged in smoking a cigar or in eating an apple or orange as we saunter along; and the smell of the flowers or of the new-mown hay, the songs of the birds or lowing of cattle in the field engage the other special senses simultaneously. We may have a companion in our stroll, and engage in conversation as we walk along, but we note every little rise of ground we must step up to, and how to avoid obstacles by lifting our feet over them. These muscular movements engage other than the ocular muscles, and other reflex arches provide the means for involuntary control. Along the spinal column there is a row of ganglionic centers by which particular reflexes are controlled. Our lungs are kept busy providing the blood with oxygen, the heart in sending blood to the lungs for purification, and to the body for nourishment, and to the brain for mental purposes; and digestive processes go right on amidst it all, and largely by reflex action all of these activities are kept up.

Whatever we may be talking about or thinking about, the reflexes proceed to function right along their special lines. But always there should be a sort of sixth sense that keeps us alert to our surroundings, and especially the approach of danger. With all of these reflexes in active operation, there is little wonder that they should exercise mutual influences over each other. All of the reflex

activities of the body, including those of the eyes, are bound into sympathetic relationships, and the general and sympathetic nervous systems are the electric cables that bring them into communication with each other. Abnormality in the functioning of the eyes may thus have a direct effect upon the digestion, or vice versa. Certainly the muscular functions of the eyes have a powerful influence, first upon each other and second upon the organic functioning of every organ. Compared with the steamship, the human anatomy and physiology, so largely controlled by automatic reflexes, is a complicated mechanism, more scientifically designed and more perfect in its functioning, but subject also to greater complexities of derangement. It is expecting too much of any class of professionals to assume that a single profession can be capable of dealing with all of these derangements and the means of relieving them. To be thoroughly competent in any field necessitates the relinquishment, to other professions, of supervision over special ones. The field of optometry is indicated by the title of this book.

CHAPTER VIII

Muscular Imbalance

Any abnormality in the structure or functional action of a muscle may be termed a *muscular anomaly*. The ocular muscles—iris, ciliary or extrinsic muscles—are subject to such anomalies. A muscle that is normal in its action, may function abnormally because an abnormal structure interferes with its normal action, or it may function abnormally on its own account. In optometry we give little attention to the anomalies of individual muscles, as we have no direct optical means of correcting them. With respect to the extrinsic muscles, our attention is centered upon their binocular poise or balance, since the neutralization of a defect of that kind may be effected by optical means. Without attributing a muscular imbalance to a specific muscle, or to a binocular pair of muscles, the fact is made apparent that there is some structural or functional inequality of different binocular pairs that give the eyes a tendency to assume abnormal positions, or relative positions, and so disturb the normal functioning of the muscles, both for versions and for ductions.

We may attribute the anomaly to the structural length of a muscle or pair of muscles, or to their attachment to the eye-balls, but it is, in that case, their *relative,* not their absolute, length or attachments; and whether it pertains to a single muscle or to a single pair of muscles, or to both muscles or both pairs, is immaterial. It is their relationship, or *relativity,* in length or attachment, that accounts for the anomaly, if it is a structural defect. The extrinsic ocular muscles are so related binocularly in effecting the versions and ductions, that a defect in one of the muscles, structural or functional, involves a pair of muscles; and a defect of one binocular pair of muscles involves the opposite pair, for it throws an abnormal functional burden upon them. It is even possible, though not probable, that the anomaly of one muscle may be compensated for by the opposite anomaly of its binocular associate, thus balancing the pair, although both muscles are abnormal, either in structure or function. To the surgeon who designs to operate for the correction of a defect, this may be an important question, but it is much less so to the optometrist.

The Homophorias

A tendency of the eyes to deviate abnormally, but equally, and in the same direction, as to the right or left, up or down, is termed a *homophoria.* As such a tendency can be neutralized by a slight turning of the head, thus allowing the eyes to have their way, little attention is paid to them. If prisms were prescribed for a homophoria, they would be of equal value before each eye and their bases would be in the same direction, the apex of each pointing in the direction of the tendency of the eyes to deviate. The classification of these anomalies is given in a previous section. Muscularly they are neutralized by a version in the direction opposite to the tendency. But, as this action would have to be maintained, it would become tiresome to the muscles. Therefore the head is allowed to turn in the opposite direction so as to allow the eyes to assume the position most comfortable to the muscles, the same as we turn the head to look at an object in an oblique direction rather than rotate the eyes in their orbits and maintain them there. The movements of the head and body co-ordinate with the versions and relieve the version pairs of muscles of much of the work they would otherwise be called upon to exercise, although their range of movement is much wider or more ample in extent than the ductions. A homophoria, although it is a muscular anomaly, is not a muscular imbalance.

The Heterophorias

If the relative lengths or attachments of binocular pairs of muscles is such as to give the eyes a tendency to turn out of normal alignment for the fixation of an objective point, or if a functional weakness of a single muscle, or of a binocular pair of muscles, tends to handicap or derange normal binocular fixation, this defect or abnormality is termed a *heterophoria.* But if the effect of the tendency is to actually turn the eyes out of normal binocular alignment, so that binocular fixation cannot be maintained, fusion of the images becomes impossible, and diplopia or double-vision results, it is termed *heterotropia* or strabismus. The muscular defects are sometimes compared as *latent* and *manifest* strabismus—that is, heterophoria as latent heterotropia, or heterotropia as manifest hetero-

phoria. In the 'phorias, as they are briefly referred to, the functioning of the muscles preserves fusion of the images in spite of the abnormal tendencies; but in the 'tropias, fusion of the images and single vision are sacrificed.

As in the definitions of the different refractive states of the eyes, or the relativity of the refraction to the axial depth of the eye, we must have a standard or datum to determine the normal from the abnormal condition. With the muscles this datum is *parallelism* of the visual axes, as required for the binocular fixation of a distant object. Its direction from the eyes, or its binocular direction, is not a factor in the maintenance of binocular fixation and fusion of the images, as that is provided for in the binocular versions of the eyes. Its distance, in connection with the binocular poise or balance of the muscles, provide the only direct factors involved. For a distant object, one at infinity, whatever its direction, binocular fixation requires that the visual axes be parallel. If such binocular fixation is obtained and maintained without special tension upon a duction pair of muscles, the eyes are of normal balance, or *orthophoric*. But if special tension on a duction pair of muscles is required to parallel the visual axes, then the eyes are muscularly unbalanced, or heterophoric.

Direction of Imbalance

The classification of the heterophoriæ is based upon the direction of the tendency of the eyes to deviate from parallelism of the visual axes, though perhaps more clearly defined by the *duction* that is necessary to maintain parallelism, such duction being naturally in the opposite directions from the tendency of the eyes to deviate. These directions are, primarily, vertical, horizontal and circular or cyclical, although the latter is essentially subsidiary. These classes are as follows:

Vertical—

1. *Hyperpo-phoria* (R. hyperphoria), a tendency of the eyes, or their visual axes, to assume different horizontal levels, the right eye tending to rotate to a higher position than the left eye.

This tendency is neutralized muscularly by a hypoper- or sumsur-duction, primarily by the inferior rectus of the right eye with the superior rectus of the left eye.

2. *Hypoper-phoria* (L. hyperphoria), a tendency of the eyes, or of their visual axes, to assume different horizontal levels, the right eye tending to rotate to a lower position than the left.

This tendency is neutralized muscularly by a hyperpo- or sursum-duction, primarily engaging the superior rectus of the right eye with the inferior rectus of the left eye.

Horizontal—

3. *Esophoria,* a tendency of the eyes, or of their visual axes, to assume a convergent position, or to turn toward each other and cross at some point.

This tendency is neutralized muscularly by abduction, an action that primarily engages the external recti muscles, and must be constant to hold the visual axes parallel.

4. *Exophoria,* a tendency of the eyes, or of their visual axes, to diverge, or rotate outward from the normal parallel position for distant vision.

This tendency is neutralized muscularly by adduction, an action that primarily engages the internal recti muscles, and must be maintained to parallel the visual axes for distant vision, and is increased for near vision.

Cyclical—

5. *Supra-cyclo-phoria,* a tendency of the eyes to assume oblique meridianal positions, so that the normal vertical meridians would be converged above, or upward.

This tendency is neutralized muscularly by infra-cycloduction, which engages the inferior oblique muscles.

6. *Infra-cyclo-phoria,* a tendency of the eyes to assume oblique meridianal positions, causing the normal vertical meridians to converge below, or downward.

This tendency is neutralized muscularly by a supra-cycloduction, which engages the superior oblique muscles.

The terms or prefixes "hyperpo" and "hypoper," which are abbreviations of the compounds, "hyper-hypo" and "hypo-hyper" are adopted to avoid the misleading terms, right and left hyperphoria,

which give the impression that the condition intended to be represented by them pertains to the eye designated, right or left, or to its muscles, and that the other eye is not involved. They fail to make clear the seemingly obvious fact that, if one eye tends to turn higher than the other, the other eye tends equally to turn lower than it, and that it is a binocular, not a monocular, condition. Therefore the term "right hyperphoria" is interpreted to mean that the right eye tends to turn upward, or "left hyperphoria" that the left eye tends to turn upward, so that we must also have the terms "right hypophoria" and "left hypophoria" to indicate the opposite tendency of each eye downward. It would be equally appropriate to have the terms right and left exophoria, and right and left esophoria, the duality of which is apparent.

It is the misleading character of these expressions that causes or validates the terms "supra-duction" of the right or left eye, and "infra-duction" of either by itself. According to these terms, the effect of a prism, base down, before the right eye, is to test the supra-duction of that eye, or the strength of its superior rectus muscle; while the same prism, base up, before the left eye, is a test of its infra-duction, or the strength of its inferior rectus muscle. But either of the positions of the prism is a test of the "Supra-infra-duction" of its muscles in combined binocular action, and not of either of them alone. If the prism, base down before the right eye alone, causes its superior rectus to contract to turn that eye upward, it also causes an equal contraction of the inferior rectus of the left eye to prevent it from rotating upward with the right, or to hold it in position while the right eye is rotated upward, for the left eye, under its version impulses, will naturally tend to rotate upward with the right eye. But, to maintain binocular fixation and fusion, it cannot be allowed to do so.

Motor-Nerve Controls

The relationship between certain of the muscular functions is usually explained on the basis of a direct connection between or proximity to each other of special nerve centers. While that explanation may account in part for some of the associations, it is far from being completely satisfactory. There is no such connection in the associa-

tion of the version pairs of muscles. To execute a rightward version of the eyes, the external rectus of the right eye is associated with the internal rectus of the left eye. The first is innervated by the 6th nerves, while the second is innervated by the 3d nerves. There has never been set up a claim that these two different pairs of motor-nerves had a common center, for they operate muscles that, in the ductions, are antagonistic to each other. A leftward version involves the same problem or enigma of muscular or motor-nerve association. And yet the association of the muscles in version pairs is the strongest association there is.

To rotate the right eye upward, or to rotate the right eye downward, is a very easy muscular action, *provided* the left eye is permitted to rotate the same amount in the same direction, and if you do not permit it, it will rotate upward or downward with the right eye without your permission. Wherever the right eye turns, voluntarily, the left eye involuntarily goes along with it, or is strongly inclined so to do, and it takes a real force to stop it. It is a primordial association, and may date back to a time when we had but one eye to rotate, for the two naturally rotate together as though they were one. We don't have to teach the eyes to function in this manner, although there is no common nerve center to account for the association of external with an internal rectus muscle. Nerve centers do not altogether explain the association, but the unexplained association functions as easily as if we had the most plausible explanation of it. So much for that.

The two superior recti muscles rotate the eyes together upward. We cannot, with any consistency say that it is because they are both innervated by the 3d cranial nerves, for this is merely a hyper- or supra-version, and if it is not necessary horizontally, for a rightward or leftward version, why should it be vertically for an upward version? But as the 3d nerves also supply the inferior recti muscles, why should not the motor stimulus sent to the superiors to cause an upward version also reach the inferiors and counteract the upward by a downward version? A nerve center must be given greater "discretion" in deciding what to do, under specific circumstances, than has ever been given to it, or than is given it by the stereotyped explanations of these associations. We must credit the nerve centers

with greater powers than is usually assigned them, to account for their effecting associate actions of the muscles. A good deal of this is due to habit or heredity, rather than to the clustering of nerve centers about a locality. Nerve centers are the product of a necessity, evolved by the necessity, rather than procreated to meet a requirement that has not as yet manifested itself, and hence we may expect that they will continue to be supplied as necessity demands them. Our anatomy and physiology is not yet *finished*. It continues to be demanded anew, and evolved by necessity. Improvements are not confined to automobiles and airships. Men are needed to evolve them and men with improved physical and mental powers. We pick up the old powers by heredity; necessity forces the new ones upon us. In a hyperpo- or hypoper-phoria, the muscles primarily involved are a superior rectus of one eye with the inferior rectus of the other, both innervated by the 3d nerves, but notwithstanding that fact, the duction power is very limited, not usually above 2△, although in version pairs they easily negotiate 40 to 50△.

Inductive Influence

The muscular functions of the eyes are not isolated, either monocularly or binocularly. They inductively influence the same functional action in each other monocularly for the intrinsic functions, accommodation and pupillary control; corresponding binocular action of the extrinsic muscular functions; and co-ordination of the intrinsic with the extrinsic muscular functions. To indicate these functional relationships we use the word "induction" in the same sense as it is employed in electricity, meaning the excitation of a passive muscular agent by an active one, although there may exist no direct cause for the action of the agent that is thus excited or incited to action. It is to this class of activities that the term "physiological" may be applied. The action is due to the physiological influence of another agent, and not to any structural defect or objective cause. The eyes are not individual in these respects, but a pair, a team, and work together.

Intrinsic Inductions

Each eye is provided with the means of controlling its own accommodative action and of exercising pupillary control over its

own pupil. The demands for such actions may be different in the two eyes, and often are different, as in anisometropia. But nevertheless there is invariably a tendency of either of these functions to act together in the two eyes, and of both to be exercised when one of them is excited. Covering one eye with an opaque screen while bringing an influence to bear upon the uncovered eye that causes contraction or expansion of its pupil, the covered eye, behind its screen responds to the influence in a less degree, but shows a sympathetic association with its binocular mate. When the accommodation of one of the eyes is excited, there is a responsive action in the other eye, though it may not be brought under the same direct influence.

In using the subjective method known as the "fogging system" for the abatement of the accommodation, more complete ciliary relaxation is obtained by applying it to the two eyes together than by applying it to either eye alone. This may be done by using corresponding lenses for the two eyes, lenses of the same power, up to the point where subjective vision, or its impairment, indicates that both eyes are in the fog, although one may be deeper in it than the other with the equal lenses. At this point, or in reducing the fog, since the accommodation has been quieted in both, at least the manifest accommodation, one eye may be covered while making the reductions one eye at a time. Even then, after each has been reduced to the required value for the best distant vision, it may be found that together they will submit cheerfully to an increase in the plus corrections found. Accommodative relaxation is thus shown to be most complete when the eyes function binocularly.

Extrinsic Combinations

The eyes are seldom turned on primary rotary axes, as the vertical, the horizontal or the anterio-posterior axes, but on some composite axes extending in the same direction through the rotary centers. The direction of rotation may be up, to the left, and inward; or down, to the right and outward. These are normal rotations, rotations that are normal for orthophoria. They are not executed by any single pair of binocular muscles, but by pairs of muscles in various combinations. For the first movement above, up, to the left and

inward, there is an upward or hyper-version, with a leftward or sinestra-version; and these are combined with an adduction of greater or less amount, depending upon the distance, or rather upon the nearness, of the object fixed. If the objective point of fixation is located, or its position relative to the medial planes, and distance from the correction plane, is fixed, the amount of each action may be stated in prism-diopters. For the versions specified, version pairs of muscles are combined; for the duction required, a duction pair of muscles are engaged; and there are also the opposite pairs of muscles acting as checks to the movement. But the net result of all of these is but the rotation of each eye upon a single axis of rotation. The visual axes are to be placed in a fixed position, and the direct rotation that fixes them in that position is made, such muscles being employed as may be required to effect the movements, monocular and binocular.

While the direct action of the oblique muscles is to rotate the eyes on their anterio-posterior axes, either in a version or a duction, their functioning in that manner is for but slight amounts, and seldom required. But they are employed chiefly for steadying the eyes in their rectilinear versions and ductions, thus keeping the retinas "square" to the image-forming incident light from the objective field of vision. In doing this they co-ordinate, but to a small extent, with the recti muscles in making rectilinear rotations of the eyes, and preventing the abnormal "rolling" of the eyes in making such movements, especially for oblique directions of the object. Hence, to effect the required versions and ductions, and hold the eyes in due receiving positions, the entire extrinsic system of muscles is in a state of perpetual activity, even in normal eyes that are in normal muscular balance. But an imbalance of the muscles or other abnormality such as a homophoria, adds a further element of tension to one or more pairs of muscles. Between all of these demands, the ocular muscles engage and consume an enormous amount of motor-nerve energy—an amount that sums up at least equal to that of the more powerful muscles of the legs, arms or body, except, perhaps, for manual labor; or the muscles of the tongue and other organs of speech by the salesman, politician or public speaker. They are more constant in their activities than any of these.

Extrinsics With Intrinsics

But the inductive influences of the extrinsic upon the intrinsic muscles, and vice versa, are of very much greater importance. Partly on account of the proximity of ganglionic nerve-centers to each other; partly from the distribution of motor-nerves from the same or different nerve-centers to the same or different muscles; partly from the identity of objective demand, or necessity of co-ordination, and the habit or practice of acting together, entailing an hereditary tendency to co-ordination, becoming fettered by necessity, there is built up certain associations between extrinsic and intrinsic muscular functions that must be taken into account in dealing optically with either.

The most generally recognized association of this kind is that between the functions by which the eyes are muscularly adjusted to changes from far to near vision, or from near to far vision. The association is between the horizontal extrinsics (the internal and external recti in duction pairs) and the ciliary muscles; and to a less degree, the iris. This association is usually referred to as that of "Accommodation and Convergence", each of which is the "effect" of a functional action rather than the function itself. Convergence is a physical or static term, without reference to the functional action that brings it about. The functional action is *Adduction,* the primary muscular factors of which are the internal recti, with the external recti acting as checks to over-convergence of the eyes. The term "adduction" is better suited to represent this factor of the association, for it may be exceedingly active without effecting any convergence whatever.

The accommodation is not a one-direction action merely, but as the term indicates, it is the functional power of adapting the refraction of the eye to objects at greater, as well as at less, distances. If the adaptation of its refraction to a less distance, by increasing the convexity of the crystalline lens, is *positive* accommodation, its adaptation to a greater from a less distance, by reducing the convexity of the crystalline lens, is *negative* accommodation. There is every reason to believe that the eye functions muscularly, but alternately, in both directions, and that passivity occurs only when an emmetropic eye views distant objects, or a myopic eye is engaged in

seeing an object at its far point. The purpose of a distant correction of the eye with lenses is to reduce accommodation to this state, passivity for distant vision, positive accommodation for a nearer object, negative accommodation for the neutralization of positive; but in extreme youth this may function slightly to neutralize myopia of a low degree.

The belief in this functional power is based upon the apparent muscular provisions for it in the variety of arrangement of the muscular fibers of the ciliary muscle, the pliable character of the triangular ciliary body, which permits it to be swerved in different directions, and the fact that its tensions upon the lens are transmitted to it by the means of a non-muscular suspensory ligament that is passive to the application of different muscular tensions or directions of tension. A better basis for the belief is, however, direct observation of its functioning in children between the ages of eight and twelve, whose actual myopia becomes apparent or manifest during that period although showing no previous indications of it. Beyond the age of twelve years the negative action merely neutralizes positive accommodation. But further than this, this negative functioning of the accommodation is associated with abduction, the same as positive accommodation is associated with adduction, but in a less intimate degree. Optically this association is confirmed by slightly "fogging" distant vision and observing its effects, especially in young people, in increasing a static exophoria or reducing a static esophoria, showing that abduction has been stimulated by the accommodative effort to neutralize the effects of the fogging lens.

Instead, therefore, of confining our attention strictly to the very threadbare subject of "Accommodation and Convergence", we may expand it to include both sides of the functional associations, or make it a full statement of the associations, as follows:

1. Adduction with +Accommodation, and
2. Abduction with —Accommodation.

These relationships do not appear in normal eyes with normal muscular balance, except for the normal functional activities due to changes in the distance of the object; and the eyes that the optometrist has most to do with are not usually normal in either, and never in both, respects. Therefore it is more important to consider the

abnormal states of the eyes both with respect to their refraction and muscular balance, in order to understand the bearing of these different functionings to each other, using the normal states merely as a basis for comparison. These different conditions may be combined as follows:

Primaries:	1 Emmetropia.	2 Hyperopia.	3 Myopia.
A. Orthophoria	A1	A2	A3
B. Exophoria	B1	B2	B3
C. Esophoria	C1	C2	C3

We may refer to these different combinations by letter and number, as to A1, B2, C3, etc.

Functional Neutrality

The reciprocal inductive influences in Class A1 offset each other, for both are equally passive for distant vision and equally engaged for near vision, and in the direction that satisfies the other. Hence, they work in complete harmony. The objective cause for 3 D. of accommodation by each of the eyes, is also the cause for 3 m-a of convergence, and this is met by that amount of adduction. Should either function be ineffective, as the accommodative function in presbyopia, this does not lessen its influence upon adduction, for their relation is nervous rather than muscular. While the eyes retain their version powers unimpaired by age, their duction power, especially adduction, gradually subsides, the same as accommodation. That is one reason for the decentration of presbyopic lenses, or the reading segments of bifocals, inward. This setting of the segments in bifocals also gives direct near vision through the centers of the segments, and preserves the neutrality of the functions in reciprocal inductive influences.

The optometrist will have few patients of this class visit him in a year, and he will be able to do nothing important for them with lenses for distance. They will come in, if for any purpose, because of defects that his lenses will not correct, such as amblyopia, foreign bodies to be removed from the eyes, perhaps temporary paralysis of an ocular muscle, or opacity of one of the dioptric media. These are not true optometric cases, but the optometrist often possesses

better facilities for diagnosing them than a physician. Amblyopia is often due to temporary causes that a physician can deal with better than an optometrist. To remove foreign bodies the optometrist should have an anesthetic for the purpose, and this he may get from a physician in his vicinity. Deep seated opacities he cannot relieve, nor has the physician any means, except surgery, of dealing with them. Local paralysis, if temporary, may be treated by an optometrist better than by a physician, for the optometrist has better facilities. The best treatment is to encourage the muscle to function, which is done by lenses and muscular exercises, both for ciliary and extrinsic muscles.

Classes B2 and C3 may be functionally neutral, as when the static defects are equal to each other. That is, when, in B2, the hyperopia and exophoria balance each other; or in C3, when the myopia and esophoria equalize each other. But these balances are rarely found. Usually one of them predominates, and then the balancing of them optically is often the important question in providing a correction that can be worn with comfort and satisfaction. It would be useless to discuss them in detail, for their variations are infinite. It is only important to note the effects of the dominating influence when they do not neutralize each other. In the following the dominating defect is placed in the first column, with its direct effects and inductive influence in the second and third columns:

Dominant.	Direct.	Inductive.
1. Hyperopia	+Accommodation	Adduction
2. Myopia	—Accommodation	Abduction
3. Exophoria	Adduction	+Accommodation
4. Esophoria	Abduction	—Accommodation

The direct effect of hyperopia, as shown above, is to accentuate positive accommodation, or innervation of the positive ciliary fibers, either for distant or near vision. The influence of this action is to inductively stimulate the muscles of adduction, primarily the internal recti, tending to neutralize or conceal a real exophoria, or to induce apparent orthophoria, or even esophoria. If the hyperopic eyes are really orthophoric, this influence may convert them into esotropia or convergent strabismus, and often does so with children in whom the

fusion sense is not developed. Hence, the correction of the hyperopia neutralizes the abnormal tendency or turning of the eyes inward.

In the second class above, in which myopia is the dominant defect, there may be combined with it, orthophoria, as in A3; exophoria, as in B3, or real esophoria as in C3. As to the action of the negative ciliary fibers, they are only effective in neutralizing the action of the positive ones, so as to produce the minimum or static convexity of the lens; but their inductive effect upon the muscles does not depend upon their effectiveness in reducing the convexity of the lens. Their stimulation for that purpose, though ineffective, inductively excites or incites abduction, tending to give the eyes an outward tendency, or exophoria. A pair of eyes that are 2 D. myopic have an accommodative far point of ½ meter, or 20 inches. If the eyes are orthophoric, they must be converged to this far point for binocular fixation. To do so there is required sufficient adduction for that purpose, as well as an additional amount to neutralize the influence of the —accommodation, exercised to hold the lens to its flattest form, as required for far-point vision, or to neutralize the influence of the required adduction in inciting positive accommodation. That is, although a pair of myopic eyes require no accommodative action whatever for their far point, they do require to be converged to it; and the adduction that is necessary for such convergence stimulates positive accommodation, which necessitates an equal negative action. To balance these contending factors, functions that would be normally inactive are forced into activity.

In the third combination, in which exophoria is the dominant factor, its direct effect is to cause adduction for distant vision, in order to fuse the images. There may be combined with the exophoria a less degree of hyperopia, B2; emmetropia, B1; or myopia, B3. As the inductive influence of the adduction is to cause positive accommodation, this covers the hyperopia, but might induce slight "physiological" myopia, so as to slightly blur distant vision. It would be more apt to do this if the dominant exophoria were combined with emmetropia. The effect would therefore be to produce simulated or pseudo myopia, which is but another name for "physiological" myopia. With the exophoria uncorrected, a pair of minus lenses that corrected the pseudo-myopia would improve distant

vision. A Chicago oculist and teacher expresses his favor of this plan of correction, rather than to prescribe prisms for the exophoria, as the minus lenses tend to harmonize the functions of convergence and accommodation. But as he also holds the idea that the prism correction of the exophoria does not influence the accommodation, it is a little hard to reconcile the two ideas. Either these influences are reciprocal or neither has any inductive influence over the other. If the myopia were real, it would tend to enhance the exophoria, or to cause pseudo-exophoria, the same as real exophoria tends to cause pseudo-myopia. If two neutralizing wrongs are better than one right, the theory of the oculist referred to might be approved. But nevertheless, in cases of this kind, a weak prism, base in, to relax the adduction, invariably improves distant vision, showing that its inductive influence upon the ciliary muscles is thereby abated. It is in cases of this kind that minus lenses are often prescribed, even for slight hyperopia, as they improve distant vision. A cycloplegic relaxes the accommodation, but a weak prism, base in, does it equally well, so why the cycloplegic? In cases of apparent weak myopia, it is always advisable to test the effect on distant vision of a weak prism, base in.

In the fourth combination, the real esophoria necessitates the exercise of abduction for distant vision, in order to maintain fusion of the images, but abates such abduction for near vision. If the esophoria is combined with weaker hyperopia, its inductive influence, since it is in the direction of stimulating —accommodation, tends to add a fictitious element to the real hyperopia. Even if the eyes are emmetropic, a pair of plus spheres, which neutralize the —accommodation or tendencies, are worn with comfort, and without impairment of distant vision. We usually take such a case to be one of weak hyperopia, and regard the esophoria as simulated. It requires a fine drawing of the lines to differentiate the two; but it will be found, eventually, that the correction of the esophoria, of a weak amount but still real, will be worn with greater comfort and satisfaction for cases of C1. But in cases of C2, the plus correction of the hyperopia should also be made. In cases of C3, a full correction of the myopia without giving attention to the esophoria is not found comfortable, but an undercorrection of it, which amounts to the same

as prescribing plus for emmetropia, when combined with esophoria, will be worn satisfactorily. As optometrists are so persistently warned against prescribing minus lenses, it is the course most regularly pursued.

Vertical Influences

A vertical imbalance of the muscles, hyperpo- or hypoperphoria, tends to give the eyes an appearance of esophoria. That is, either of the vertical imbalances produces a tension on the four vertical recti muscles, two of them to neutralize the imbalance and the other acting as checks, so that all four of them exercise a traction upon the eyes. As all four of these muscles are anchored to the cartilaginous ring that surrounds the optic foramen, which are nearer to each other than the eyes, or to the nasal sides of the orbits, their traction upon the two eyes tends to converge them. In the adduction of the eyes they co-ordinate with the internal recti, which is one of the reasons for its amplitude. Hence, it is advisable to eliminate any vertical imbalance, or to neutralize it, before testing the horizontal. A vertical imbalance may also be influenced, to a less degree, by a horizontal one, and the oblique muscles are also mixed up in both vertical and horizontal imbalances. Hence, to determine the true muscular condition of a pair of eyes, especially for oblique directions of vision, not only must refractive or accommodative influences be neutralized, but the influence of different duction pairs of the extrinsic muscles upon each other. A version of the eyes upward, downward, to right and to left, will disclose the effects of these influences. The versions should be made after the muscles have been balanced for distance, by having the patient turn the head and face in the opposite direction.

Near Vision Balance

When a pair of orthophoric eyes are fixing a small target at the reading distance, or at any near distance, adduction is necessary; and if the target is above or below the horizontal medial plane, a hyper- or hypo-version of the eyes is also necessary to direct vision to it. Both the adduction and the version are normal for the position of the target. Primarily that is the normal functioning of the muscles, or

what they are intended to do. But if a pair of orthophoric eyes are converged to a near target, naturally they have a tendency to turn back to parallelism, or to their primary positions for binocular single vision of a distant target. This is not a heterophoria of any sort, either exo- or eso-phoria. The eyes also accommodate positively for such near vision, and the ciliary muscles, which are contracted for the purpose of adapting the refraction to the near object, tend to relax. Any muscle that is contracted for a normal purpose *tends* to relax. But we do not call this special contraction of the ciliary muscles for near vision as indicating hyperopia, although their contraction for distant vision is hyperopia. It takes a plus lens in either case to relax the ciliary muscles. But that lens for distance represents hyperopia; but for near vision it represents, if required, presbyopia, not hyperopia.

It seems to have become the general practice to give the eyes muscle tests for near vision, and to call whatever is found by the names,

1. Orthophoria-for-Near Vision or Fixation,
2. Exophoria-for-Near Vision or Fixation,
3. Esophoria-for-Near Vision or Fixation, etc.

These terms are analogous to similar ones expressing the refraction for near, as Emmetropia-for-Near, Hyperopia-for-Near, and Myopia-for-Near, a nomenclature we would at once repudiate. The amount of each would naturally depend upon "how near" the object or target is, so that the accepted standard reading distance of $\frac{1}{3}$ meter, or 13 inches, is taken to represent it. Any pair of eyes that accepts a pair of +2 sphs. for distance with normal vision unimpaired by them, will naturally accept plus lenses of a higher value for 13 inch vision. Either eye alone will accept +3 D. in addition, although both eyes together may not, because of muscular influences. Are the eyes therefore 2 D. hyperopic for distance and 5 D. hyperopic for near vision? Or have they greater hyperopia in a near than in a distant test? If so, the term "hyperopia" loses much of its significance. It is equally true of "exophoria-for-near" or esophoria-for-near." But as these expressions are pretty generally used, it is important to know just what the users of the terms mean by

them. Therefore, in the discussion of "Muscle Testing" they will be explained.

The Cyclophorias.

The cyclophorias are usually the product of symmetrical oblique astigmatism, or astigmatism in which the meridians of maximum refraction, and also of minimum, are either equally divergent upward or downward, as the vertical and horizontal positions of these principal meridians will not give the object an oblique appearance. Examples of such astigmatism are those in which the maximum meridians, or meridians of greatest refraction, may be, for the right and left eye, as follows:

Right, 105°; Left, 75°
Right, 120°; Left, 60°
Right, 135°; Left, 45°
Right, 150°; Left, 30°
Right, 165°; Left, 15° or vice versa.

The axes of the correcting cylinders are in one or the other of these principal meridians, according to whether the cylinder is plus or minus, and the sum of the two axial positions is always 180°. The astigmatism that the cylinders correct may be considered to be produced artificially by an opposite cylinder in the same axis. As the eyes cannot accommodate cylindrically, but only for one meridian of the astigmatism, it has no inductive influence upon the muscles. The action is direct, if it is anything, and therefore inductively it is the same as simple hyperopia or myopia in its inductive influences.

CHAPTER IX

Static Phorometry

(Muscle Testing)

The determination of the binocular poise or muscular balance of a pair of eyes requires that all influences, except the normal ones that pertain to them, be removed or eliminated. Therefore, for the purpose it is best to employ a target that, at the standard distance of 6 meters or 20 feet, is also at the intersection of the vertical and horizontal medial planes. This distance is regarded as infinity, and as it is directly in front of the eyes, the muscular action required to fix it is minimized or reduced to 0. But there is no outward or objective indication whether the muscles are at rest or not. That has to be determined by test. To make such tests we require a suitable target, and optical devices of various kinds.

The Target

The kind of target we employ depends upon what optical device we intend to use with it. It must be rather small, but large enough to be clearly seen at the distance, and be located in a field with which it is in clear contrast, such as white on black, black on white, or a luminous spot in a dark field. A single line, or two lines at right angles, since they are narrow in one direction, though extended in the other, make a suitable target for some purposes. When the target is to have position nearer to the eyes than the standard 20 feet, it should be correspondingly smaller, or may be printed letters on a card, arranged in a vertical or horizontal row. But a near test of the muscular balance involves the normal use of the muscles, and such normal use of them is of course to be regarded and discounted from the findings. The balance of the muscles is best determined by a distance test, in which such normal action of the muscles is not involved. We may then determine the effects of nearness of the target upon them.

The stimulus for the binocular fixation of the distant target, by which the muscles are normally engaged, proceeds from the fusion of the images. Whatever the target, its image appears upon both retinas. If the two images are of the same form, color, extension

and general size and appearance, and naturally take corresponding positions upon the two retinas, they will be fused into one visual impression or effect. The demand for such fusion will excite the muscles to the required action, if any action on their part is necessary. Therefore, to determine whether such fusion is due to normal relaxation of the muscles, or to their abnormal action, the stimulus for fusion of the images must be eliminated. This is done in various ways and by different devices and targets. We can either make the images dissimilar in appearance, by the distortion of one of them, or we may so deflect the light into one of the eyes that the image is greatly displaced, making it impossible for the muscles to so rotate the eyes, or one of them, as to bring them to the relative retinal positions required for fusion. By thus breaking up fusion, causing diplopia, we eliminate the normal effects of the fusion sense as a control over the muscles. As a consequence, the muscles relax and the eyes assume the positions most comfortable to them.

When diplopia has been brought about in this way, or one of these ways, we measure the deviations of the eyes by the prism value that is required to restore the normal relative positions of the images, although not restoring their normal appearance, or the appearance of the one image that has been distorted, discolored or displaced for the purpose of breaking the control of fusion over their relative positions. Whatever this prism value may be, and whatever position it is required to stand before one of the eyes, or divided between the two of them, it measures the *tendency* of the eyes, or of their visual axes, to deviate from parallelism, both in the direction of the prism power and for its value in prism diopters; and this tendency represents the muscular tension that is required to hold the eyes, or their visual axes, in the parallel positions required for the binocular fixation of the target.

Device and Target

As stated, the target used depends upon the devices we intend to use with it; or the device we employ depends upon the target to be employed. The principal optical devices, some of which belong to the same class, and the target that is used with them, are as follows:

1. Opaque cover test, to obscure one eye, any target.
2. Red disc, to give target that color for one eye, spot light.
3. Maddox rod, to make target a "streak" of light, spot light.
   Cone test, to make target circle of light, spot light.
4. Double prism, to double vision of one eye, single line.
5. Single prism, to displace image in one eye, cross lines.

The most generally used of the above devices are the 3d and 5th, with a red disc, usually to contrast the images, or make the patient's designation of the relative positions of what he sees simple and clear, as "the red light or line is to the left or right, or above or below the other one". Device 4, the double prism, is also favored by many practitioners, although it is less dependable than Device 3, used in the same way. It is also used with a line target, making two lines of it, which are contrasted with the single line seen by the other eye.

While the use of these devices, and the reading that is obtained and what it means with respect to muscular balance, are very simple, it is in the *interpretation* of the reading that many optometrists become confused and are led to erroneous conclusions, or misled to them. As the refraction of the eyes is involved in them, or the influence upon them of the accommodative function is to be regarded, this is a further complexity, which becomes a perplexity to the optometrist. When muscle tests are made for the reading or other near distance, there are still further complexities and perplexities to be taken into consideration, and the combined effects of all of these is such as to naturally have a discouraging effect. If we add to all of these the "mistaken teachings" to be found in some text books, and in the pronouncements of notable lecturers upon the subject, the path of the student of optometry is not an easy one to the mastery of this special field. To clear some of the perplexities that surround the subject, let us discuss one of the simplest of muscle tests.

Binocular Test

If, with a pair of eyes binocularly fixing the target at 20 feet, a single prism of 7△ is placed, base down, before the right eye, double vision of the target will usually result. If the target is a pair of cross lines, each 6 cm. in length, with 3 cm. arms extending from the center or crossing point, this prism should normally place one

cross directly above the other, separating the horizontal lines 7 cm., or making them appear as parallel horizontal lines at that distance apart. This effect would separate the ends of the vertical lines 1 cm. but maintain their alignment. A slight variation from this position is not to count, for it may be due to a slight inclination of the prism, or to the fact that normal adduction for the 6 meters (1△) is relaxed. If, therefore, the two targets seen appear in this relative position, the prism accounts for it and the appearance is normal.

As two crosses are seen, one directly over the other, vision may be directed to either one of them, or shifted from one to the other. When looking at the upper of the two targets the right eye only is fixing it, for the left eye does not see it. When looking at the lower target the left eye only is fixing it, for the right eye does not see it. But you will not be visually conscious of this fact. It will seem to you, when you are looking at either, that both eyes are seeing it, that you are binocularly fixing it. But if, while looking at the upper target, you cover the right eye with an opaque disc, that target will disappear; but it will not do so if you cover the left eye in the same way; and if, as you are looking at the lower target, you cover the right eye, you will continue to see the lower target as before; but covering the left eye in the same manner causes the lower target to disappear. When looking at either target your vision of the other is indirect, and therefore less distinct.

The fact that in fixing one of these targets you seem to be seeing it with both eyes, is probably due to a reflex of the visual sensation from the fovea of one eye to the fovea of the other. That is, in looking at the upper target, its image is placed upon the fovea of the right eye only; but its sensory effect in the brain is reflexed to the fovea of the left eye, so that visually it seems as though each of the foveæ were receiving the same image, as in normal binocular fixation of it. But while fixing one of the two visible targets, the target indirectly seen by the other eye is also reflexed to the fixing eye, but to an area of the retina of that eye that corresponds with its position upon the retina of the eye that sees it indirectly. So that, either by direct fixation of one of the eyes and a sensory reflex to the other eye; or by indirect vision of the non-fixing eye, and a sensory reflex to the fixing eye, we may be said to be seeing both targets with each eye, or to have binocular vision of both of them. But vision of either

target would be less emphatic than real binocular single vision of the cross, for there is the light impact upon but one retina for vision of either of them, and but one visual message from retina to brain.

As the fovea will accommodate an image of .02, or 2△, and the image of a 6 cm. target at 6 meters fills but an angular space whose tangent is .01, or 1△, the image of the given target, on the fovea of the eye fixing it will extend but about half way across it, or leave an unoccupied border of 3 cm. all the way around the cross that is a blank on the fovea. Hence, the cross that is not fixed by either eye is imaged with one of its arms extending over the objective foveal area 2 cm., so that the crossing point of the lines of the cross is, in the non-fixing eye, entirely off or outside of the foveal area. This is the effect of the 7 cm. displacement of one of the images by the 7△ prism. This will impair the distinctness of vision of the cross that is not fixed by either eye, for it is seen by indirect vision only. Its sensory reflex to a corresponding area of the retina of the fixing eye is therefore correspondingly dim. But by shifting fixation from one to the other of the targets, this relationship is reversed. If either eye had less acuity of vision than the other, its fixing vision would be reduced accordingly.

But the purpose of producing vertical diplopia in the above manner is not to determine the normal consequences of it, but to observe the abnormal ones. This would be manifest by any mis-

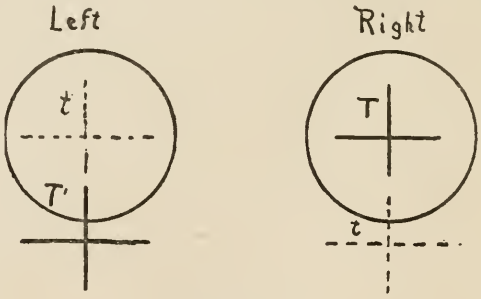


FIGURE 30.

Circles represent areas of foveal vision at 6 meters for right and left eyes. Foveal vision (not images).

Black cross-lines represent vision of cross-line target of 6 cm. as seen at 6 meters, with 7 △ prism, base down, before right eye, when vision is directed to the upper target. Real vision.

Dotted cross-lines represent reflex vision of target as seen by the other eye.

alignment of the vertical lines as seen in the two targets, for visually there are two of them. A horizontal separation of the two vertical lines, such that a prism, base to the right or left, over either eye, would be necessary to put them in normal alignment, proves that the visual axes are not in normal parallelism for distant vision. They are either convergent or divergent, as the vertical prism does not account for their horizontal separation. Unless there is some inductive influence, such as accommodation for distance, either positively or negatively, to account for it, separation of the vertical lines horizontally indicates a horizontal imbalance of the muscles. It is one variety of heterophoria.

Diagnosis of Imbalance

If the eyes that are binocularly tested as above have been optically corrected of any refractive defects, so that there is no accommodation exercised for distant vision, then the direction of deviation of the visual axes is determined from the direction of relative displacement of the two vertical lines of the targets. If the vertical line in the upper target, which is seen by the right eye only, appears to be at the right of the vertical line in the lower target, which is seen by the left eye only, such displacement or diplopia is said to be *homonymous*. But if the vertical line of the upper target appears to be to the leftward of the vertical line in the lower target, then the displacement or diplopia is said to be *heteronymous*. That is, in homonymous diplopia, the right eye sees the right hand target, the left eye the left hand one. In heteronymous diplopia these positions are reversed, or the right eye sees the left hand target and the left eye the right hand one. These distinct and never to be confused results indicate that the eyes deviate in a direction *opposite* to that of the visual appearance. Applied to the binocular test above described, the results are as follows:

1. *Homonymy.* If the vertical line in the upper target appears to the rightward of the vertical line in the lower target, the vertical line in the lower target will of course appear to the leftward of the vertical line in the upper target.

This is homonymous displacement or diplopia, for each eye sees the object in its own direction, rightward for the right eye, leftward

for the left eye, and naturally the same distance of separation between them.

But the above direction of displacement or diplopia indicates that the visual axes of the two eyes are *convergent,* or that they cross each other at some point, or would do so if extended forward of the eyes.

They therefore have the tendency to *converge* and cross each other when binocularly fixing a distant object, but are restrained from doing so by the exercise of the function of *abduction.*

This function (abduction) is exercised primarily by the external recti muscles, and they must be kept under tension to maintain parallelism of the visual axes, as required for binocular fixation of distance, under these conditions.

This tendency of the visual axes to converge, even for distant vision, but which is restrained by the function of abduction, is termed *Esophoria,* which is an abnormal tendency of the eyes to converge.

2. *Heteronymy.* If the vertical line in the upper target appears to the leftward of the vertical line in the lower target, that line in the lower target will of course appear to the rightward of the same in the upper target.

This is heteronymous displacement or diplopia, for each eye sees the object in the opposite direction from its own position, the right eye seeing the target to the leftward, the left eye seeing the one to the rightward.

But the above direction of displacement of diplopia indicates that the visual axes are *divergent,* or that their crossing point, if projected, is back of the eyes. The eyes turn outward, and must do so to produce such displacement.

They therefore have the tendency to *diverge* in that manner when fixing a distant object, but are restrained from actual divergence by the exercise of the function of *adduction,* which holds the visual axes parallel.

This function (adduction) is exercised primarily by the internal recti muscles, and they must be kept under tension to maintain parallelism of the visual axes, as required for the binocular fixation of a distant object.

This tendency of the visual axes to diverge for distance, but which is resrained by the function of adduction, is termed *Exophoria.* It is an abnormal tendency of the eyes to turn outward, or away from each other.

Esophoria Measurement

Since, in esophoria, the displacement or diplopia horizontally is homonymous, the upper target, seen by the right eye, will appear to the rightward of the lower one, seen by the left eye. The two vertical lines may be put in alignment by a prism that moves the upper target a sufficient distance to the left. The prism, for that purpose, must be placed before the right eye, with its base to the right or outward, as the deviation of light toward the base of the prism will appear to move the object or target toward its apex. If it takes a 3△ prism, base out before the right eye, to align the vertical lines of the two targets, that is the measurement of the displacement or of the esophoria. Placing the same prism (3△) base to the left, or outward, before the left eye moves the lower target to the rightward, or toward its apex, the same distance, and this will also put the vertical lines of the cross in alignment. If there appears to be some slight difference between the two positions of the prism, this is probably due to the "slant" of the prism, for a prism has the least deviating effect when refraction is equal at its two surfaces, and it must have a fixed slant for this purpose.

As the 3△ prism, base out before either eye, corrects the displacement of the vertical lines, causes them to align with each other, but one 3△ prism, in either of these positions, measures the imbalance or esophoria. It indicates that in the binocular fixation of a distant object, or that in distant vision, the eyes require to exercise 3△ of abduction. This puts a continuous tension and strain upon the external recti muscles. However, as the eyes are never required to turn beyond parallelism of the visual axes, this is not a heavy muscular burden to bear. It makes convergence of the eyes for near vision that much easier, as a relaxation of the external recti muscles will allow the eyes to rotate according to their tendency, inward, with less than normal adduction by the internal recti. Unless

there are "reflex" effects upon the accommodative function more disturbing than the strain upon the external recti for distant vision, an esophoria is allowed to go uncorrected. It is an imbalance that is frequently fictitious, due to the inductive influence of the accommodation in uncorrected, perhaps latent, hyperopia, and will disappear with the correction of the hyperopia. But a true esophoria, one that is due to a malattachment of one of the muscles to the eye, may not be disregarded; especially if it tends to exact the blurring of distant vision by an over-plus correction.

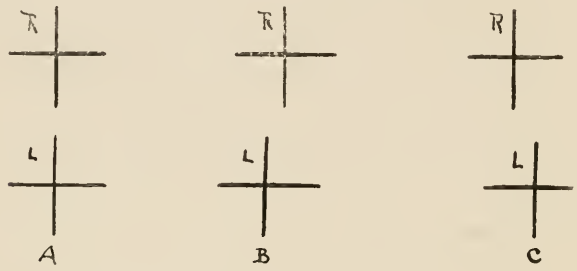


FIGURE 31.

Binocular vision of cross-line target, with 7 Δ prism, base down, before the right eye, causing vertical diplopia of 7 Δ.
A, Normal alignment of vertical lines for above, showing horizontal orthophoria. B, Homonymous misalignment of vertical lines, showing esophoria. C, Heteronymous misalignment of vertical lines, showing exophoria.

Esophoric Induction.

The inductive influence of a real and dominant esophoria, though it may be ineffective in that direction, is hyperopicward. That is, because of the functional action of abduction to maintain fusion of the images for distant vision, the crystalline lens is made to assume its least convexity. This is not merely a *relaxation* of the ciliary muscles, but an active muscular force, negative accommodation, that holds the lens down to its flattest or least convex form. A plus lens for distance is usually acceptable in such a case, although it blurs distant vision. The reason for this is that it makes the eyes artificially myopic, and myopia and esophoria are the best of pals. It makes near vision, at least a comfort; for not only do the eyes

tend to turn inward or converge, without exercising the function of adduction, but the myopia, whether natural or artificial, relieves them equally of exercising normal accommodation for the distance. If the eyes are myopic, without a plus lens to make them artificially so, then the esophoria and myopia are happily joined for near vision; but normal distant vision is out of the question.

If the eyes are emmetropic, requiring no distant correction, then a prism correction of the esophoria offers the only means of relief to the strain upon abduction, the tension of the external recti, provided normal distant vision is to be attained. In myopia, with esophoria, the myopia and esophoria must both be corrected for comfortable distant vision. The correction of the myopia alone will not suffice, for the inductive influence of the esophoria will make a full, if any correction of it at all, unacceptable. The reason for this is that it is a breaking away of boon companions, pals, esophoria and myopia, whose functional comradeship may not be disturbed with impunity, although both handicap or make impossible normal distant vision. In hyperopia, with esophoria, the plus correction of the hyperopia will be greedily accepted, for even an over-plus correction is acceptable. But if hyperopia is the dominant factor, then the real esophoria is likely to have a fictitious, or pseudo-esophoria, added to it. We are speaking here of the inductive influence of the esophoria, not that of hyperopia or any other refractive condition.

For near vision, esophoria with myopia is no handicap, provided balance between the subnormal accommodation and adduction results for ordinary near vision work. This would be about in the ratio of 6△ of esophoria to 1 D. of myopia, which places the far-point of accommodation and adduction together at a distance of one meter from the eyes, or from the correction plane of the eyes, which is the plane of the lenses, or about from the crest of the bridge of the spectacle frames in which the lenses are mounted. Then, for the ordinary reading distance of 13 inches, there would be necessary co-ordination of the functions, as 2 D. of accommodation would be required for each eye, and 12△, or 2 meter-angles of convergence. This exact ratio is of course unnecessary but the accommodative function is more exacting than that of adduction, and an approximate ratio of that amount would balance the two functions, making

relative adduction (or convergence) and accommodation harmonious for near vision.

The establishment of harmony between the functions is sometimes of greater importance than the correction of either of the defects individually. Those who forswear the use of prisms altogether, and harmonize them on the refractive side only, will find it necessary to prescribe minus lenses for emmetropes or hyperopes for distant vision, or plus lenses for emmetropes or myopes, according to the initial relativity of the functions. If a prism correction is acceptable, and saves one from the above incongruous practice, he should use them. They are just as essential in some cases as spheres or cylinders.

Exophoria Measurement

As exophoria, in the above muscle test, shows the upper target to the left of the lower one, the right eye sees this left hand target. To bring the vertical lines of the two targets into alignment by a prism over the right eye, it must be placed with its base to the leftward or apex to the rightward over that eye, so as to move the target in the direction of alignment. This position is base inward, or toward the nose. Over the left eye the prism would have to be reversed, but this would place the prism base inward over that eye. The latter moves, or appears to move, the lower target to the leftward, or in the direction of alignment of the vertical lines of the two targets with each other. It is obvious that it is as many △'s of displacement one way or the other, or that the displacement is *relative,* and that it is the same distance from one to the other as it is from the other to one. The prism that, base in before the right eye, aligns them, will also align them if placed base in before the left eye.

If a 5△ prism is necessary in one case, it is necessary in the other also. Although either prism is placed base in, that is a reverse position for the two eyes. One moves the upper target to the right, the other moves the lower target to the left. If we divide the prism into two equal segments of 2½△ each, and place one of these half-values over each eye, but both with their bases inward, we will get the same effect; for the prism before the right eye moves the upper target 2½△ to the rightward; while the prism before the left eye

moves the lower target 2½△ to the leftward, and this unites the vertical lines of the targets the same as if one of them had been moved the entire distance. While this is not the best test for horizontal imbalances, because a vertical imbalance may disturb the relative positions of the two targets vertically, it is perfectly clear what these misalignments mean. They clearly indicate that the visual axes are not parallel, but are, in this case, divergent, showing exophoria.

Many optometrists are puzzled over the apparent inconsistency of the outward turning of the eyes causing crossed visual diplopia. But it is very simple and obvious. If the right eye sees the target to the leftward, its image is necessarily upon the temporal side of its retina, or temporalward relative to that seen by the left eye; if the left eye sees the target to the rightward, its image is necessarily upon the temporal side of its retina, or temporalward relative to the position of the image on the right retina; or both are temporalward from the foveas. The eyes have a position, or relative positions such that the two foveas are inward or nasalward. Hence the visual axes, which begin at the foveas, must spread or diverge in front of the eyes, as they begin to do so within the eye balls or globes. The eyes are turned in the opposite direction from that in which the targets appear. If the targets are deviated outward (homonymy) the eyes deviate inward; if the targets are deviated inward (heteronymy) the eyes deviate outward. Or, in other words, homonymy of vision is heteronymy of deviation; and heteronymy of vision is homonymy of deviation.

Whatever exophoria appears, under a muscle test, is genuine. It is even more, seldom or never less, than it appears. It may be concealed by the inductive influence of dominant hyperopia, converted into apparent orthophoria, or even manifest apparent esophoria. But this is the inductive influence of hyperopia upon muscular balance, or apparent muscular balance or imbalance. If the exophoria is dominant, it will be that which influences the apparent refraction instead of the other way about. It seems fairly obvious that, if the muscular condition causing adduction or abduction, inductively influences the refraction or accommodation, the refractive condition or accommodation will inductively influence the muscular condition, or apparent condition. There is this difference, however,

positive accommodation has its high point or maximum power, varying with age; and its recession from that high point downward takes it to zero or 0, and the latter is negative accommodation. But in

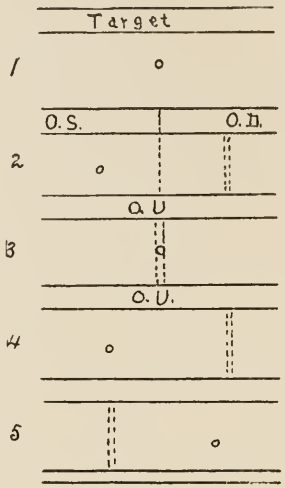


FIGURE 32.

Objective appearances in Maddox rod test of horizontal balance of muscles: 1, target as 6 meters, small bright light; 2, as seen by right and left eyes, vertical streak in right eye; 3, as seen in orthophoria, light in streak; 4, as seen in esophoria, homonymous displacement; 5, as seen in exophoria, heteronymous displacement.

muscular balance, the zero point is between the two opposite functions of adduction and abduction, and the functions extend in either of two opposite directions from this zero point.

Exophoric Induction

The influence of exophoria upon the refraction or accommodation of the eyes is myopicward. That is, since it excites the function of adduction to obtain and maintain binocular fixation of a distant object, the internal recti muscles are under tension for distance, and greater than normal tension for near vision, the same as the ciliary for hyperopia. The stimulas for both of these actions is supplied through branches of the 3d pair of cranial nerves, the motor oculi. As a reflex action, the excitation or innervation of one of these

functions naturally excites or stimulates the other, and through a common ganglionic reflex nerve center. This is the accepted explanation of their close association, "Accommodation and Convergence" as they are usually termed. A better designation of the factors of association are "Positive Accommodation and Adduction" for *adduction* is the function and convergence is the effect. In the adduction of a pair of exophoric eyes for distant vision, which merely parallels the visual axes, positive accommodation is inductively excited or stimulated the same as by adduction for near vision.

But the development of this association has been through the *necessity* for common or joint action for near vision. Nearness of the object normally excites the accommodation to maintain focalization of light at the retinas of the two eyes, and thus make the retinal images clear. It also normally excites adduction to converge the two eyes and maintain binocular fixation, so as to maintain fusion of the images and single vision. The two functions therefore normally co-ordinate, each with the other. This has made it a universal *habit,* and *heredity* perpetuates the habit from generation to generation; and these combined influences, one of which is the fact that the two functions are stimulated by motor nerves having a common reflex ganglionic origin or nerve center is but one. In fact it may have been, or probably was, the physical necessity, followed by the development of the habit, and these with heredity to perpetuate them, that evolved, in human anatomy and physiology, the neuromuscular association of the two functions.

But the fact that, from some inequality of attachment of the muscles to the eye-balls, adduction for distance is demanded, does not lessen its inductive influence in exciting the accommodation to joint action with it. As exophoria puts such a demand upon adduction, the accommodation is stimulated by it to a greater or less degree. What the consequences of this inductive stimulation of the accommodation are depends upon the refractive condition of the eyes. If the eyes are hyperopic, and for an equivalent amount, then the two functional actions will be happily joined. They are natural pals, and go hand-in-hand over the entire range of vision, from distance to near. There is an intrinsic demand upon each function, and

each inductively co-ordinates with the other. Although each is optically abnormal, their abnormalities fit each other, and they become boon companions in exercising the muscular functions involved in vision. But, they will not pleasantly accept separation. Like Jack and Jill, or John-Anderson-my-Jo-John, they climb life's hill together. So, if Jack comes tumbling down, and even though he may break his crown, Jill comes tumbling after.

Functional Equilibrium

The two functions are in accord, unison or equilibrium when, for a width of 6 cm. between the eyes, there is 6△ of adduction necessary by the eyes jointly, for 1 D. of accommodation by the eyes individually. This puts the two functions in the ratio of 6△ to 1 D., or 6 to 1. Measured in meter angles, there is 1 m-a of adduction to 1 D. of accommodation by each eye. Although the accommodation is exercised by the eyes individually, their associated action is about as intimate as the joint action of adduction. When, therefore, there is 6△ of exophoria to 1 D. of hyperopia in each eye, the two functions are in normal equilibrium. As adduction and accommodation increase normally in the same ratio for near vision, this equilibrium is maintained for all distances of the object, or *relative* adduction and accommodation is normal, although neither may be individually normal. The two functions are then, not only pals for distant vision, but for near vision also. We can get along very well however when this relationship is quite far from normal, as the functions adapt themselves to a considerable difference. Like a person with a short leg, a slight hip adjustment equalizes the two.

When the hyperopia exceeds this relative value, it becomes the dominant factor in the relationship. But if, with exophoria of a considerable amount, there is weaker hyperopia, emmetropia or myopia, the exophoria is dominant. It tends to nullify or conceal the hyperopia, makes the eyes appear emmetropic or slightly myopic, so that the plus lenses that correct the eyes individually are not comfortable or acceptable binocularly; the emmetropic eyes are made to see distant objects better with weak minus lenses; and the myope demands more minus than the eyes individually call for. There are

some practitioners, medical as well as optometrical, who have such an antipathy to prisms that they prefer to prescribe minus lenses in these cases; and some who don't know any better, which also includes oculists as well as optometrists. The oculist who uses drops is apt to find out that less minus or none is called for. The optometrist could find it out in a much simpler way, by trying the effects on distant binocular vision of a weak prism (2△ to 4△) base in, held before either eye. Improvement will then show that, by relaxing adduction, the ciliary tension is also relaxed, proving the myopia to be fictitious to that extent. It is *physiological* myopia, which is but another name for false-, simulated- or psuedo-myopia.

In the same way that exophoria affects the apparent refraction of the eyes, hyperopia affects their apparent muscular balance, when it is the dominant factor. The accommodation required for distant vision excites the positive ciliary fibers, and their innervation and the innervation of the internal recti are simultaneous or synchronous. Hence, a muscle test for distance with the hyperopia uncorrected, does not relieve the ciliary of the action required to focus the target. But since, under a muscle test, there is no longer the fusion stimulus to determine what muscular action is necessary to fuse the images, the eyes and the muscles respond to any extraneous influence that may be brought to bear on them. The accommodative action inductively excites adduction, so that, instead of assuming their positions of rest, adduction turns the visual axes toward each other. Some and perhaps all of their tendency to diverge is overcome; or they may even be converged slightly. The relative positions of the target will then show but a part of their actual exophoria; or it may all be covered by the adduction and show apparent orthophoria; or if the association is intimate, esophoria may be apparent. It is fictitious, not a real structural imbalance of the muscles in that direction. This also is *physiological* esophoria, which is but another name for false-, simulated- or psuedo-esophoria. But it is the most frequent form of esophoria encountered, the most prevalent form. In children it is apt to cause such adduction to manifest itself as convergent strabismus, which is none the less manifest, in spite of the static exophoria. A full correction of the hyperopia will remove this influence, provided we can find it under these circumstances.

In the same way that excessive near work may result in ciliary spasm, not only in hyperopia and emmetropia, but in weak myopia, ciliary action that is due to the inductive influence of exophoria may foster it. Hyperopia ceases to be the dominant factor with the correction of the manifest amount with plus lenses; but with the exophoric influence remaining, a concealed element of ciliary action remains, and this connot be "fogged" out with repression plus lenses. But, we can relax and repress the abnormal adduction by prisms so that only ciliary spasm, due to hyperopia, is left. Hence, *repression lenses,* to fully relieve all influences tending to excite or incite ciliary action, must embody both factors: the plus sphericals to directly relieve ciliary action, and the prisms base in to relieve and repress abnormal adduction, due to exophoria. The prisms will relieve the ciliary of the influence of exophoria much more readily than sphericals, but neither without the other is complete.

Vertical Tests

In describing tests of the vertical muscles for imbalance, the Maddox rod will be employed to make the tests, instead of the single prism. It is perhaps a better test for the horizontal imbalances also, and a figure to show the different results of this test of the horizontal meridians and muscles is shown on another page. The target for a Maddox rod test is a small but clear light at 6 meters, one that is 1 cm. in diameter, if distinct and in a dark field, will show the deviations or displacements better than a larger one. If the Maddox rod is multiple and the aperture in the opaque disc is round, better results are obtained than with the single rod. If the Maddox rod is of uncolored glass, the other eye may be covered by a red disc, so as to facilitate the patient's description of its location. The Maddox rod converts the target into a fine but bright *streak of light.* When the rod is vertical, or has the rod or ridges vertical over the eye before which it is placed, that eye will see a horizontal streak of light, while the other eye sees the bright spot openly and naturally.

As the visual sense does not recognize the identity of the two visual effects, but visualizes the result as "a light and a streak," there is no natural reflex stimulus to bring two such dissimilar im-

ages together, or into the relative positions for fusion. Hence, if they assume that position, with the streak running through the light, or the red light is in the streak, it is because there is no tendency of the eyes to deviate from normal parallelism for distant vision. But if the red light takes a position above or below the streak, that indicates that the visual axes are not parallel, but that one is directed higher than the other. If it should be the right eye that is directed higher than the left, the left eye would of course be directed lower than the right. It is a relative matter altogether. Binocular attention or vision can be fixed upon either, but of course only one of the eyes sees either streak or light by direct vision. We may, however, by the use of a prism, base up before one of the eyes, or base down before the other, bring the two together. They do not *fuse,* but merely cross corresponding subjective points of fixation in the two eyes, or rest upon them.

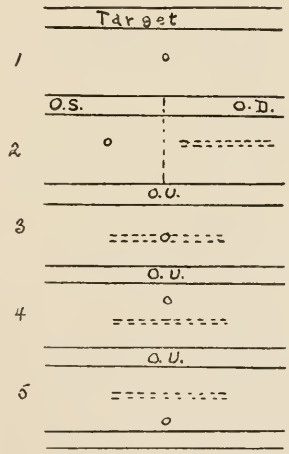


FIGURE 33.

Objective appearance in Maddox rod test of vertical balance of muscles: 1, target at 6 meters, small bright light; 2, as seen by right and left eye, horizontal streak in right eye; 3, appearance in muscular balance or orthophoria; 4, as seen in hyperpo-phoria, right eye higher than left; 5, as seen in hypoperphoria, left eye higher than right.

If the Maddox rod is before the right eye and the red disc is before the left eye, and the red light is in the streak centrally, then the visual axes are parallel, and there is no tendency of the visual axes to deviate relative to each other vertically. This indicates vertical orthophoria or binocular balance of the eyes or muscles, for there is no fusion stimulus to cause them to assume that position. If the eyes are hyperopic, accommodation, by inciting adduction, may put a slight tension on the four vertical muscles, but it will be equal on all of them, if the object is straight before the eyes, and this will cause no vertical deviation of the visual axes relative to each other. If the object or target is near, this also will cause a slight tension on the verticals, but it will be equal. Version of the eyes in any direction may disturb the equilibrium, but only to a slight extent, if the muscles are normally innervated. Paralysis or paresis of a vertical muscle would make normal version in the direction of the affected muscle impossible, and this immobility would cause streak and light to separate.

If the red light is not in the streak, but above it, the left eye is directed relatively lower than the right eye, or its fovea is raised above a corresponding position with that of the right eye, so that the image occupies a relatively lower position in the left eye than in the right eye, and is projected to a position relatively higher than the image or streak in the right eye. As the fusion sense is not in control of their positions, the left eye *tends* to turn lower than the right and does so turn in the test. This is but to say that the right eye has a tendency to turn higher than the left, and does so turn in the test. This imbalance of the muscles has been termed *right hyperphoria,* which is an indictment of the right eye as the eye at fault. But, as the deviation and the tendency are merely relative, it deserves a more significant designation. We use the term *Hyperpophoria* to designate it, and *Hypoper-phoria* to designate the opposite imbalance. This avoids the unwieldy compounds "hyper-hypo" and "hypo-hyper" as prefixes to the general term 'phoria. The common designation for the latter imbalance is *left hyperphoria,* which attributes the imbalance to the left eye and discharges the right eye from any responsibility.

Muscular Neutralization

To neutralize a tendency of the right eye to turn higher than the left eye, and to fuse the images in spite of such tendency, there must be a contraction of the inferior rectus of the right eye and the superior rectus of the left eye. Naturally the tension of these two muscles to hold the visual axes on the same level is equal. It is a "duction," for it is "An involuntary muscular action that normally rotates the two eyes equally in opposite directions." In this case it merely restrains the eyes from abnormally rotating in that manner, as a pair of muscles always does in any 'phoria. The duction required for hyperpo-phoria may be termed *sumsur-duction* or hypoperduction, for the duction required to overcome a 'phoria, in any direction, is in an opposite direction from the tendency. Hence, hyperpophoria puts a muscular tension on the inferior rectus of the right eye and superior rectus of the left eye. The opposite tendency, hypoper-phoria, puts muscular tension upon the superior rectus of the right eye and inferior rectus of the left eye, and is *sursumduction,* or hyperpo-duction, as you choose.

An imbalance of the eyes vertically, or of the vertical muscles, as all four of them are involved in one way or another, puts an undue tension and strain upon one or the other of the vertical duction pairs of muscles, the opposite pair being passive or non-resisting, except to restrain the tension pair from over-action. This tension must be kept up to prevent the eyes from deviating, which would at once result in vertical diplopia, seeing two objects for every one, one above the other. As the vertical duction powers, sursum-duction and sumsur-duction, are quite limited, not from "weakness" of the muscles, but inability to innervate them in the peculiar manner required (the superior rectus of one eye with the inferior rectus of the other) a slight imbalance, measured by a 1△ or a 2△ prism, may cause more discomfort than a much greater horizontal imbalance. There are rare cases in which such an imbalance reaches 3, 4, 5 or more △'s, that the muscles overcome; but usually in such an inequality of tension, one of the eyes turns in the direction of its tendency, producing a vertical strabismus, and causing repression of vision in

the deviating eye, or at least the use of the eyes alternately for visual purposes. The continuous repression of vision in one of the eyes causes its acuity of vision to wane, or the eye to become amblyopic.

Prism Measurement

The degree of the vertical imbalance is determined by the value of the prism required, in the test, to move the light into the streak, or the streak to the light. In hyperpo-phoria the prism is placed base down before the right eye or base up before the left; and in hypoperphoria it is placed base down before the left eye or base up before the right. The prism value that is required, in either case, before one eye, is the measure of the imbalance in prism diopters. No attention need be paid to any slight difference in their values, if the measurement is made in both directions, that is, first base down before one eye and then base up before the other, for such differences, if any, are due to the different slants of the prism in the mounting, on one side and then the other. If a 2△ prism, base down before the right eye, brings the streak up to the light, a 2△ prism, base up before the left eye, will bring the light down into the streak. The imbalance is then 2△ of hyperpo-phoria (or right hyper-phoria as it is generally called). Turning both eyes upward or downward back of the prism and red disc should cause but slight change. To turn the eyes in this manner with a fixed target, the head must be tilted in the opposite direction to maintain fixation.

Much greater caution is required for prescribing a prism or pair of them for a horizontal imbalance than for a vertical one. There are scarcely any inductive influences to falsify or masquerade a vertical imbalance. There is much greater certainty of giving the required relief to the muscles in prescribing a prism correction of vertical imbalances than for a horizantal one. The question of the apportionment of the value of the prism between the two eyes is one of mechanical convenience or advantage. The entire value may be before either eye, base down before one or base up before the other; or its value may be equally divided between the two. In the fol-

lowing, three different arrangements for a 4△, correction of hyperpo-phoria is shown,

1. 4△ base down, before the right eye, only.
2. 4△ base up before the left eye, only.
3. 2△ base down over right, 2△ base up over left.

The symptoms that an uncorrected vertical imbalance produces are asthenopia in any of its forms, eye distress or pain, headaches and general organic derangement, from reflex influences, and very often an unconquerable sleepiness that makes night reading or study impossible. In attempting to do night work or reading, the reader soon finds that his eye-lids become too heavy to allow the eyes to be kept open, and he goes to sleep over his book. The effect of a prism correction of his hyperpo- or hypoper-phoria is magical in its effects in relieving this influence. With the prism correction he reads for hours unaware of the time as the hours slip away. A 1△ correction has a relieving effect apparently out of all proportion to its value. As lenses of weak power, spherical, cylindrical or compound, are often more effective in relieving asthenopia than stronger ones, although they may have but slight effects in improving vision, so the correction of a weak vertical imbalance is effective in the same way.

A prism or prisms, prescribed for permanent wearing, are not given for the purpose of paralleling the visual axes, or to "straighten" the eyes; but to relieve the muscles under strain because of the imbalance. Instead of straightening the eyes, the prism allows the eye to deviate according to their tendency, thus putting the subjective points of fixation at the foveas out of exact alignment with the objective point. But the prism so deviates the course of light from the objective point that it falls upon the subjective foveal points, thus putting the images in correct relative positions for fusion. The prism has no muscles, nor has it motor nerves to be put under stress and strain. Its form and refraction take these muscular and nervous tensions off of the physiological organs, so that the eyes may exercise their functions normally and without pain and distress. Improved vision, though important, and usually brought about by lenses, is

less important than the relief of muscles of abnormal tensions, and motor nerves of exercising abnormal control.

Oblique Muscle Tests

To determine whether the oblique muscles are in balance or not, it is necessary to eliminate the operation of the fusion control that causes a horizontal line target to appear horizontal, and a vertical line target to appear vertical, to both eyes, so that they visually coincide. Perhaps the simplest way to do this is by placing the double-prism before one of the eyes, with the bases of the prisms extending in the same direction as the line-target. This will make the single line of the target appear double to the eye over which the prism is placed. The double line will appear as two parallel lines, separated according to the power of the double prisms, and the distance of the target. Two 1△ prisms in the double-prism, for a 6 meter distance of the target, would separate the parallel lines .02 of 600 cm. = 12 cm., one up and the other down, or one to the right and the other to the left, both being "displaced" equally 6 cm. in opposite directions.

If the target is a horizontal line, and the double prism is placed before the right eye, with the line between the prisms horizontal, that eye will see the target as two parallel horizontal lines. The left eye, uncovered, or covered by a red glass disc, sees the single line, but not displaced if the muscles are in balance, and normally it should be midway between the two parallel lines, and parallel with them. It is the parallelism of this third line, seen by the left eye, with the other two, or their parallelism with it, that determines whether the oblique muscles are under equal tension or equally relaxed. Its nearness to one of the parallels, or less distance from it than the other, indicates a vertical imbalance, but not a cyclo-phoria. If, however, it has a slanting direction, relative to the parallel lines, this indicates a cyclophoria, made manifest by the test. There is no prism action that would rectify this effect, as a prism, base down or up, would merely raise or lower what the eye it covers sees, two lines or one. There is no kind of lens, except a cylinder, to change the slant of the target as seen by either eye; and without astigmatism to correspond to it in

value, the cylinder will impair vision of the line or lines corresponding to its axis.

If the single line is slanted between the parallels so that its leftward end is upward, or nearer the upper parallel, while its right end is downward, or nearer the lower parallel, we may say that its left end shows depression of the temple side of the left eye, rela-

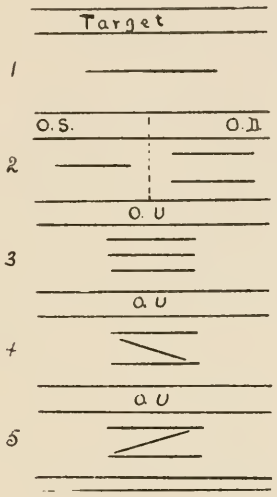


FIGURE 34.

Objective appearance in double-prism test of balance of oblique muscles, double prism before right eye: 1, target a horizontal line; 2, as seen by right and left eyes; 3, appearance in normal balance of obliques; 4, as seen in infra-cyclo-phoria; 5, as seen in supra-cyclo-phoria.

tive to the nasal side of it; or depression of the temple side of the right eye, relative to its nasal side. This is a rotation of the eyes such as to cause their vertical meridians to converge downward, or diverge upward. As the fusion control is suspended, this indicates *Infra-cyclo-phoria,* and therefore in the binocular fusion of the images the tension and strain falls upon the two superior oblique muscles, to exercise the Supra-cyclo-duction that is required to cause the images to take the relative positions required for their fusion. The opposite slant of the single line would indicate *Supra-cyclo-*

phoria, and require Infra-cyclo-duction to neutralize it, or a tension and strain upon the two inferior oblique muscles.

A horizontal or vertical imbalance of the muscles can be neutralized by a prism, for a simple prism has plane surfaces, and therefore neither converges nor diverges the rays of light, nor directly affects or influences the refraction of the eye, nor its focalization of light from an object at any distance. But, as we can use only a cylindrical lens to alter the direction of a line, and cylinders are required to correct astigmatism, and if not so required they produce artificial astigmatism, we cannot employ them for the two purposes at the same time, unless it happens that the correction of astigmatism with a pair of cylindricals also neutralizes a cyclophoria; or the neutralization of a cyclo-phoria with cylinders having oblique axes also corrects astigmatism, which is very unlikely in one case out of a thousand or more. Apparently there is nothing we can yet do to correct cyclophoria, although we can diagnose it, and locate the muscles under strain. Some one may yet have the happy idea for the solution of this problem in optometry.

CHAPTER X

Dynamic Phorometry

In static phorometry, which naturally precedes any dynamic test, we endeavor to *quiet* all lateral muscular activities or functions, having or tending to have, an inductive influence upon the particular muscles whose static condition, or functions, we purpose to test. Therefore we use a stationary target, located on the medial line of vision directly before the eyes, and at as great a distance as our testing space will allow and have the patient hold his head erect and stationary. We also correct any error of refraction found, to the end that vision shall be as perfect as his acuity of vision will permit, and the accommodation be inactive. No lenses are used except those that exercise a quieting effect upon all of the muscles save only those that are directly involved in the test to be made, thus insuring a correct static finding.

But, in dynamic phorometry, we purposely engage other muscular activities and functions, for definite amounts, while making the tests, and for the purpose of determining the *scope* of their influence, and its effect upon the *range* of the function under examination, which may operate more or less fully when co-ordinated with another function or acting in opposition to it. These dynamic methods are also used to *develop or* increase the range of a function, and neutralize any *dormancy,* or tendency in that direction, of the function we are examining. The exercise of a function in this way tends to free it of influences that tend to bind it down and limit its range of normal activities, and to throw off temporary paralysis or paresis, restore circulation of arterial blood to the muscle, and to stimulate the discharge, through the lymphatics, of effete matter that is clogging functional powers. But essentially, it is a cultivation of the neuro-motor control of the muscles in the exercise of their functional offices of all kinds.

Muscle Tests for Near

A duction pair of muscles, apparently normal in a distance test of their balance, may still show weakness of functional power in a test on a near target. If the target is still upon the medial line, its nearness engages normal accommodation and adduction. If the

eyes do not exercise due accommodation for the distance, vision of the target is sure to be impaired for such near distance; and unless adduction that is normal for the distance is exercised, diplopia will result, homonymous diplopia the same as shown in exophoria. But we may neutralize the accommodative demands by plus lenses to correspond in power to the normal demands of such nearness upon the accommodation of each eye. While these lenses eliminate the normal demand for accommodation, they do not neutralize, unless decentered, the normal demand for adduction, as it will still be necessary for the function of adduction to continue in order to converge the eyes to the near object, or binocularly to fix it. Otherwise there will be diplopia.

The effect of the plus lenses to neutralize the accommodation for the nearness of the object, +3 sphs. for 13 inches, unless decentered a considerable amount, so that the converged visual axes pass through the optical center of each, will be to increase the convergence required, as they will act as prisms, base out, for such near vision. These lenses will not prove acceptable to an emmetrope with an ample fund of accommodation, not because the required adduction will be beyond reach, but because its inductive influence upon the accommodation will stimulate positive accommodation in spite of the lenses, which would blur vision of the near target. It is here that the negative ciliary fibers would be exercised to check the action of the positive fibers, and hold the crystalline lens to the flat form required to focalize the near object through the +3 sphs. It is perhaps these counter-activities that make a pair of lenses of this nature and power uncomfortable or intolerable, except to a presbyope, whose accommodation has been weakened by age, and not comfortable even to him unless decentered inward. If the distance correction were also plus, these effects would be augmented. In myopia, the minus lenses required for a distance correction, would be reduced in value by the plus element that neutralizes the distance of the target; but the adduction, unless the lenses were decentered outward, would still influence the accommodation in the same direction and for the same degree. There would require to be a balancing up of the functions to make near vision through the distance correction, less the .+3 neutralizers, tolerable.

But adduction for the near target may also be neutralized by prisms, base in. For a width of 6 cm. between the centers of rotation, a pair of 9△ prisms would be necessary, or a single prism of 18△, base in, before one eye. Without the +3 sphs. the adduction would be neutralized optically for a target at 13 inches; but the eyes would have to accommodate 3 D. each for the nearness of the target, and this would inductively excite adduction, tending to cause diplopia. To prevent this consequence, which is more intolerable than blurred near vision, the external recti would be called into functional action to check such adduction as the accommodation incited. Clearly, we must neutralize, in whole or in part, both functions or neither. But, to observe the operation of these functional relationships, we must make the muscle test for near, as we have made it statically for distance. To do this most effectively, the target should be one that is composed of intelligible characters, such as a row of letters in a horizontal line, with a vertical row of letters crossing it, such as the following:

B
F O G
X

Fig. 35.

These letters can be adapted, in size, to the 13 inch distance, or be of varied sizes for those having greater or less acuity of vision. A prism of sufficient power, base down over either eye, will produce vertical diplopia, and we can see, or the patient can tell us, the exact relative positions of the two targets seen. The vertical diplopia is naturally attributed to the prism, and there is no possibility of fusing the two images. The words "BOX" will normally appear one above the other, but in direct vertical alignment. If they do not assume this relative position, but are separated in a horizontal direction, it is proof that, without a prism to account for it, there is horizontal deviation of the visual axes from the directions they are required to take to fix an objective point at 13 inches. The visual axes are converged more or less than the amount required for fixation at this distance. If the prism is placed base down before the

right eye, the right eye will see the upper, the left eye the lower target. We may represent the above target by a simple cross or plus sign, +. The different relative positions may be represented as follows:

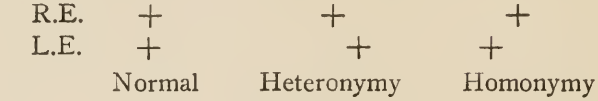


Fig. 36.

What these different effects mean, in a near test, remains to be considered. As diplopia has been produced by the single prism, base down, before the right eye, there is no longer fusion control exercised. Either eye may fix the target by merely directing visual attention to it, in the direction it appears, to that eye, to be. The other eye, although it does not see the target in that direction, will follow it, though with uncertainty, as it cannot fix definitely what it does not see at all, except as a sensory reflex to its foveal area of fixation. Both eyes together will accommodate for the distance, although they do not binocularly fix it in that position, if they have equal and sufficient power of accommodation. There will be no visual recognition but that both of the eyes are fixing a single one of two targets. When vision is directed to the other target, or the target as seen by the other eye, both of the eyes together turn toward it, but only the eye that sees it fixes it with certainty, the other eye being the uncertain one; but both eyes will accommodate for it as before. If visual acuity, or accommodative control, is better in one eye than the other, the target actually seen by the better eye will appear clearer than for the other. But this is not a circumstance to impair the muscle test for near.

Adduction for Near

If, in spite of the elimination of fusion control, by the prismatic displacement of one of the images, sufficient to cause diplopia, the two targets seen appear to be in normal alignment, the one directly above the other, then adduction for such near distance is being exercised an amount that is normal-for-the-distance. But this is really

an abnormal functioning of adduction, since there is no fusion stimulus for it, although the object or target is near. It will not often, if ever, take place. There are, however, two lateral incentives to adduction, although the most important direct one is taken away. These are,

1. The accommodation required to be exercised, directly by the fixing eye and indirectly by the other eye.

2. The visually observed and subjectively felt nearness of the object, made manifest by other senses.

If, therefore, in our test at 13 inches, there is heteronymous diplopia, the upper target being to the left of the lower one, and it requires a 6△ prism, base in, to align the upper and lower targets, this shows that that amount of adduction increase is necessary to normally align them. If the p. d. is 6 cm., making normal adduction for 13 inches 18△, the adduction actually exercised is $18 - 6 = 12$△. That is, notwithstanding the elimination of the fusion stimulus, other influences cause adduction of 2/3 the normal amount to continue to be exercised, or causes a loss of but ⅓ of the normal amount. While from the readings of the test (heteronymous diplopia) and the fact that it takes a prism value base-in to restore normal positions, (corresponding to exophoria in a distant test) it is a little anomalous to call it exophoria-for-near. Exophoria is a muscular abnormality. This is not an abnormality, but a natural result, something to be expected or anticipated, under the circumstances. We are surprised that there should be so much adduction rather than that there isn't more, with the main-spring of adduction eliminated. It is apparent that the other two influences are quite strong.

Instead of "exophoria-for-near" the 6△ that adduction falls short of for the distance, is an abatement of that amount, due to the want of the normal stimulus of fusion as a controlling factor. Its resemblance to exophoria is that it takes a 6△ prism, base in, to put the targets seen in normal alignment for the near distance. But, it resembles esophoria also, for there is a tendency of the eyes to converge for near notwithstanding the absence of fusion stimulus. If this amount to 12△, this corresponds to the inductive influence of

hyperopia, or the accommodation for distance in hyperopia, to cause the eyes to converge, and is a *physiological* action. That is, rather than exophoria-for-near, it is physiological esophoria, a convergence of the eyes due to the influence of normal accommodation for a near target, as well as to the visual recognition of the actual propinquity or nearness of the object. What we call it does not matter very much. It will vary for different patients; but it throws an important light upon the functioning of the muscles, and the relationship of the functions.

As the influence of the accommodation is the principal cause for adduction for near, under a near muscle test, we may eliminate it, or attempt to, by a pair of plus spheres for the distance of the target, in addition to the distance correction of the eyes. This would be +3 spheres for a 13″ distance. As the stimulus for accommodation of right and left eyes is for targets in different positions, one above the other, these spheres should be acceptable, provided the target is the 13″ distance from them. That is, they should relax all accommodation, both of right and left eye, and thereby eliminate the influence of accommodation upon adduction. We would then naturally expect to find the adduction reduced, and the so-called "exophoria-for-near" increased. But what we do find in a particular patient depends upon the personal equation. As the amount of physiological adduction may vary for different patients, so the effects of relaxing it with spheres may vary, both for different patients and for the same patient at different tests. As it is very easy to put these spheres in a decentered position, thus increasing or decreasing the apparent adduction, that factor has to be reckoned with, as it may be misleading.

The chief purpose of a muscle test for near is not to determine the balance or imbalance of the muscles for near with fusion eliminated, but the functional activity or passivity of the muscles under such test. The more active they are the greater will be their adduction or the less their so-called exophoria-for-near. With the accommodation eliminated, there will still be adduction of a decreased amount, and in what is then left we have the influence of mere *propinquity* of the object, as both the fusion stimulus and the accommo-

dative influence are eliminated, or as nearly so as we can do it with prisms and spherical lenses for the near target. If there is muscular paralysis or paresis of any of the horizontal muscles, the test will show motor-nerve control is wanting or subnormal. We do not need to stop with the prism value, base in, that measures the lack of adduction for near, but increase the prism value to a point that carries it over into the homonymous field, or puts the upper target as far to the right of the lower one as it is without any prism, to the left of it. A prism, base in, will increase abduction, or abate adduction, the same in a near test as in a distance test, and with or without diplopia; but it must be placed over the eye that is fixing the target to observe effects. The comparison of a near muscle test, or its results, with what we have previously determined to be the real muscular equilibrium of the eyes by a distance test, either confirms or does not confirm the distance finding, and then we may search out the cause of it by a test of the duction powers of the muscles on a distant target by regular methods. The target, for near tests, should be one that engages the accommodation as previously suggested.

Special Dynamic Methods

The muscular functions of the eyes may be stimulated for a distant, as well as upon a near target, by the use of lenses to excite these muscular activities. As the means of inciting accommodation for distance are independent of those for inciting the ductions, there is lacking in each individually the co-ordination that is obtained by the natural excitation that is produced on both classes of functions by a near target. But by a simultaneous stimulation of both, for equivalent amounts, an artificial co-ordination of the functions may be brought about. It is much simpler, however, to employ the natural method of nearness than to employ lenses for the purpose and as it is the method by which the functions are habitually excited, more reliable results are obtained. It will be found convenient in some instances, to combine the two methods at the same time.

If a pair of eyes are emmetropic, either naturally or artificially

so, minus spherical lenses before the eyes stimulate positive accommodation for distance. That is, the lenses that correct myopia, when not required for that purpose, make the eyes artificially hyperopic; and the plus lenses that correct hyperopia, when not required for that purpose, make the eyes artificially myopic. This is the effect of the plus values that are added to the distance correction for the relief of deficient accommodation, or the correction of presbyopia, for the lenses do not, of course, supply the eyes with the accommodative power, whose deficiency is the cause of inability to adapt the eyes to near vision. Accommodation may therefore be stimulated for distant vision by minus lenses whose power is in excess of actual myopia, or by the reduction in power of their plus correction for distance.

The adduction function may also be stimulated for a distant target by a prism, base out, before either eye, or divided between them. When the eyes are in normal balance, orthophoria, a prism, base out, excites adduction for the distant target, and adduction, like all of the ductions, is binocular. It is a function that is engaged in by a pair of duction muscles, never by a single muscle, although but one of the eyes may be required to rotate for both of them. It is this fact that many optometrists and refractionists of all kinds often have a mistaken idea of. The refraction of the eyes is monocular, and must be corrected in each eye separately; but the ductions are binocular, and the pair of muscles primarily involved are either stimulated or relaxed together by a single prism before one of the eyes. This may be proved in a simple way by the prism-and-cover test, on a pair of eyes in normal balance in the vertical or horizontal directions, and both objectively and subjectively, and as follows:

Prism and Cover Test

With a distant small light as a target (a white card on a dark or contrasting back-ground will answer the purpose) and with the trial-frame mounted for the insertion of lenses or not, as necessary,

the patient or subject binocularly fixes the target and sees it single. Then the left eye is covered by an opaque disc, the right eye continuing to fix the target alone. We then place an 8△, base out, before the right eye. The right eye will turn to the leftward, or toward the apex of the prism, to continue to fix the light in its apparently new position. But the left eye, under the cover, may be seen to turn to the leftward also, with the right eye, although it does not see the target or anything in that or any direction. It merely turns with the right eye, making the movement a leftward version of both eyes, although the right eye only is fixing the target in the position it appears to be as seen through the prism. Now, if the left eye is un-

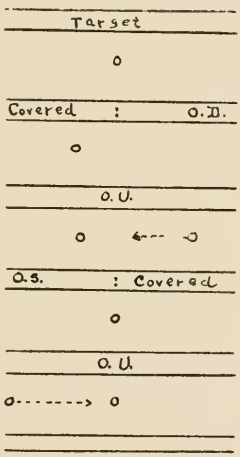


FIGURE 37.

Prism and Cover Test: 1, target as binocularly fixed; 2, as seen by right eye through prism; 3, as seen when left eye is uncovered; 4, as seen by left eye uncovered; 5, as seen when right eye is uncovered with prism before it.

covered, it will see an apparently new light, but to the rightward of the direction toward which it is turned. This new light will be there but momentarily, but move to the leftward and "fuse" with

the other light. This apparent movement of the "new" but really original light is due to the rotation of the left eye back to a position for fixing it. As the left eye turns rightward the light will appear to move in the opposite direction, or leftward, for the left eye alone sees it. The right eye remains fixed upon the only light it sees, the light that is displaced by the prism.

To effect these changes the left eye is rotated rightward, and primarily by its internal rectus muscle. The right eye, which naturally is inclined to accompany the left eye in its rotation rightward, is not allowed to do so, but is restrained from so doing by its internal rectus muscle. Consequently, the muscular tension is put upon the two internal recti muscles, simultaneously and for an equal division of the muscular labor involved—the internal rectus of the left eye to rotate it back to the position of fixation of the target in its original position, and the internal rectus of the right eye to restrain it from rotating rightward with the left eye. This, then, is merely an adduction of the eyes, participated in by both eyes, although the left eye only makes the excursion of 8△ to the rightward. The two internal recti muscles participate in the adduction jointly, not severally, as is always the case in any duction of the eyes. Removing the prism from before the right eye causes both internal recti muscles to relax together. Covering and uncovering the right eye, before which the prism stands, would merely be a repetition of the test, except in changing from right to left and left to right in the description of effects.

Motion Tests

When the static tests have been made, showing orthophoria or heterophoria of a given kind and amount, a dynamic test may be made in either of two ways:

1. By movements of the target while the face is fixed in position, so that the eyes will rotate together to maintain fixation, or

2. With the target in a fixed position, having the patient turn the face in different directions, causing the eyes to turn in the opposite direction for fixation.

If, under such a test, the two images maintain their relative positions, both eyes are executing the version together, although the two may not be in the fusion positions for any direction. On the other hand, that eye which sees its target or image change positions relative to the other, or to move more rapidly to right or left, up or down, is either stationary or lagging behind the other. In this way the muscle that is not functioning normally is located.

Such a defect of functional action cannot be corrected with a prism, as it is a weakness of functional action. A prism correction, if attempted, would merely confirm its weakness. What it needs is a course of exercise or training, so as to restore the weak function to normal activity. Only static imbalances of the muscles may be corrected by prisms. Dynamic inactivities are improved by muscular exercise, and this applies to the versions as well as the ductions. A static imbalance is structural in character, so that exercise does not help it, or even tend to overcome the imbalance.

Rotating Prism Test

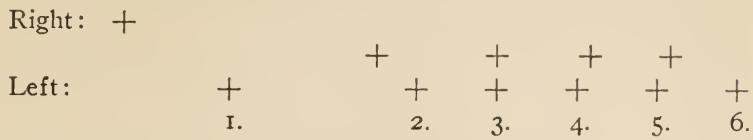
When the eyes are binocularly fixing a small but distinctive target at reading distance (13″), normal accommodation for it is 3 D. and normal adduction for fixation is 3 meter angles, and from 5½ to 6½ times as much in prism-diopters, according to the distance between the centers of rotation, which is practically the same as the pupillary distance. For the average width of 6 cm. it is 18△. The placing of a weak prism, base down or up before either eye, is sufficient to cause diplopia. A 5△ prism will often be sufficient, but a 10△ is very sure to be. If it is placed before the right eye, base down, that eye sees the upper target of the two. But the diplopia releases the adduction exercised for the nearness of the target, and the eyes usually diverge from it, causing the upper target to appear to the

leftward of the lower one, which is heteronymous diplopia. How far the upper target appears to move to the leftward of the lower one depends on how fully the internal recti muscles relax, or adduction is abated. The prism has produced only vertical diplopia, so that it accounts only for vertical separation. The horizontal separation comes from physiological activities or inactivities of the muscles.

To make the rotating prism test, the prism (10△) should be in the forward cell of the 3-cell trial frame. This provides a place for such sphere or cylinder as may be required to correct the refraction of either eye, but the cylinder, if any is required, must be placed in the back non-rotating cell. The handle of the prism may be bent outward so as not to interfere with its rotation in the frame. The target for this purpose should be a small cross, its bars being vertical and horizontal to enable the patient to clearly report effects. To make a distinct separation of the two targets seen at this distance, the vertical bar should not be longer than 3 cm. and may be much shorter provided it is distinct for the distance. As the fusion control is quieted by the diplopia, there will be no muscular action to disturb the apparent positions of the targets as seen. But a rotation of the prism in either direction will displace the upper target in the direction the apex of the prism turns. We may turn it in either direction, but it must be turned in the direction of base in to bring the upper and lower targets into alignment.

Slowly rotating the prism in its cell in this direction, its apex is successively at 105°, 120°, 135°, 150°, 165° and 180°, as well as at all intermediate positions. As the rotation proceeds the two targets approach each other, both vertically and horizontally, for the prism, by the rotation, is gradually acquiring power, base in, and as gradually losing power, base down. At 120° it has 7½△ power, base down, or has lost 2½△ of its original 10△ in that direction; but it has acquired the 2½△ power, base in. At 135° it has 5△ base down and 5△ base in, or what it loses in one direction it acquires in the other. By the downward and rightward movement of the upper target it will eventually arrive at the position directly above the lower one, putting the vertical bars in vertical alignment, but the horizontal

bars still separated vertically. These changes referred to, and further ones, are indicated by the following:



At 1 the targets are quite widely separated, the vertical separation being due to the prism action; the horizontal heteronymous separation showing merely that without fusion control, less than normal adduction for the distance of the target will result. But the distance of horizontal separation will vary for different persons. At 2 the apex of the prism is perhaps at 120°, and this is due to the power of the prism being oblique, ¾ down and ¼ in. At 3 the targets are in alignment, the upper directly above the lower, but only half of the original vertical separation and no horizontal displacement. This result will be in the neighborhood of axis 135°, for there is, at that point, still 5△ base down, and that is too much usually for sursumduction to overcome. There is no necessity for adduction to be exercised at all, for the targets are in vertical alignment. This indicates that the adduction due to other influences than fusion are effective for about 13△, while the 5△, base in, exercised by the prism does the rest. But this factor is a varying one. At 4 the upper target has passed over to the other side of the lower one, and is but slightly above it. The next movement will bring it within the range of sursum-duction, and that duction will make horizontal adjustment possible, so that fusion takes place between 4 and 5 or 5 and 6, and there is only the one target to be seen.

With all lateral factors eliminated, so that the functioning of the accommodation for the distance of the target and the gradual shifting of the prism power from base down to base in are alone involved as dynamic factors, the assumption of the relative positions of the target shown in number 3, or in vertical alignment, when the apex of the prism is at or near 135°, indicates normal adduction for near under these dynamic influences. If fusion of the images takes place when the apex of the prism reaches 150°, or thereabouts, this

indicates normal functioning of all of the recti muscles involved, both horizontally and vertically. The initial position of the upper target will vary somewhat for different persons and that may be considered as modifying the above, but only slightly. If a 5△ prism is used, fusion should take place at number 3, for only 2½△ of sursumduction would then be necessary to bring the upper target down to the lower one, while an equal amount of abduction, or the abatement of that amount of adduction, due to other influences than fusion control, would bring the two targets together horizontally, or "fuse" the two images. This would reduce the adduction from 13△ to 11½△ for the 13″ distance of the target, which may be done without compromising the accommodation, or if it does, relax it, as it would tend to do. These tests are principally important in affording the optometrist the opportunity to observe the workings and associations of the functions.

Dynamic Skiametry Test

This is really a test of the refraction of the eyes while they are accommodating and converging for a near target, but shows the relativity or potentiality of the associated functions. The usual methods of applying this test are to have the distance of the operator, and mirror, the same as that of the target, or the target attached to the mirror, and to shadow test the eyes while they are converging and accommodating for it. Then target and mirror are both brought nearer or farther from the eyes being shadow tested by a movement of the operator to a nearer or farther position. It is assumed that in converging for the near target, a co-ordinate degree of accommodation will be exercised, and that a plus lens or pair of them will not relax it, except accommodation in excess of the normal amount for the distance. Therefore, whatever plus lens may be necessary to neutralize the shadow movement is a measure of such excess accommodation, and therefore of the hyperopia. It brings the excess out by loading the function of accommodation down with more than it can do, and so reveals the excess, or makes it manifest by the shadow movements thus uncovering the latent hyperopia.

In the method we describe this plan is varied. The operator takes any convenient distance from the patient, 1 meter, 2/3 meter, ½ meter, or even a nearer distance, according to the clearness with which he can observe the reflex movements. He provides himself with a small target, about the size of a trial case lens, mounts it upon a handle similar to that of the hand retinoscope, having the small letters or characters on one side of it and the dots to be counted upon the other. Holding the target before his left eye, the patient is asked to count the dots or to read the small letters upon it, and while he is doing so the optometrist quickly shadow tests each eye. The target thus serves as a "blind" for the left eye as soon as he has made the reflex appear in the patient's pupil. If in this position motion is *with* the plain mirror, he knows that, although endeavoring to accommodate for the distance, under the urge of an equal degree of adduction, the patient is not accommodating the normal amount for the target. He must converge for it to prevent diplopia, but accommodation is less imperative in its demands, so the accommodation *lags,* or is less than the equivalent convergence. Instead of inserting glass lenses before the eye to neutralize motion, a simpler and more convenient method is used, as follows:

The target is moved toward the patient while the operator remains at his fixed distance. This he does by simply carrying it forward, toward the patient. The small letters and dots make larger

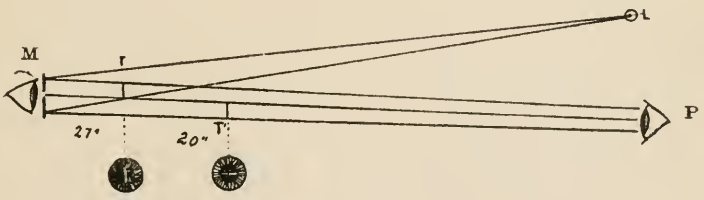


FIGURE 39.

Dynamic Skiametry Test. Working distance of operator, 1 meter. Target at 27" shows neutral band vertically; target at 20" shows neutral band horizontally; lens before eye, +2 sph. Results: add +.50 to vertical and +1.00 to horizontal, making Rx + 2.50 sph. ⊃ + .50 cyl. ax. 90.

L, source of light; M, mirror; ⊃, operator's eye; P, patient's eye at 1 meter; T, target at 27" from P; vertical neutralization; T', target at 20" from P, horizontal neutralization.

images upon the retinae, although they may be focalized less perfectly than at the operator's working distance; but the patient will converge to the nearer distance and endeavor to increase his accommodation. That the combined action (accommodation and convergence) are effective is shown by the fact that in this way the shadow movements are neutralized and may be made to move *against* the mirror. With the subjective effects upon the vision of the patient, his vision of the target at the nearer distance, we are not interested, except as a means of *enforcing* increased accommodation, or in making the accommodation supply the increased plus required to neutralize the shadow movements in the pupils, the objective effects. That the method is effective in doing so is proved by the fact that with the advancement of the target the point of reversal in both eyes advances, and soon shows neutral reflex motion in the pupil of one or both eyes. Assuming that the working distance is 1 meter, the target may have to be moved forward to a distance of 27 inches (66 cm.), or to a position 20″ (50 cm.) or even to 16″, 13″ or 10″ (the equivalent of 40 cm., 33 cm. or 25 cm.) from the patient to bring this about. We have thus enforced an accommodative increase of the dioptric differences between the position of the target and the working distance of the operator.

Dioptric Equivalents

The equivalents, in dioptric increase of accommodation, for these distances of the target, or for any distance of it required, are readily worked out. If the working distance is 1 meter or 40 inches, and the operator and target are in that position, but motion of the reflex or shadows is *with* the mirror, the target is advanced, thus engaging co-ordinate action of the functions of accommodation and adduction or inciting them to action. For the respective positions the dioptric values of the increase in accommodation are respectively as follows:

1. For target at 40″, neutral motion, no increase, emmetropia
2. For target at 32″, neutral motion, .25 D. increase hyperopia

3. For target at 27″, neutral motion, .50 D. increase, hyperopia
4. For target at 23″, neutral motion, .75 D. increase, hyperopia
5. For target at 20″, neutral motion, 1.00 D. increase, hyperopia
6. For target at 16″, neutral motion, 1.50 D. increase, hyperopia
7. For target at 13″, neutral motion, 2.00 D. increase, hyperopia

The method of reducing to dioptric equivalents is merely to reduce the target distance from the patient's eyes to its dioptric equivalent, and from it take the dioptric equivalent of the operator's working distance. The difference thus obtained represents the probable amount of *latent* hyperopia, or hyperopia that is concealed from ordinary subjective or even objective discovery.

It may be questioned how the inciting of the accommodation to greater activity in this way can possibly bring out a latent element, for an increase of accommodation may be said to be "on top" of that previously exercised, while a latent element, due to spasm, is at the bottom of it—the part that fails to relax or respond to plus lenses. That is a question in philosophy, and neither the originator of this method, nor the writer set up as philosophers. Perhaps the latent element *filters* up through the body of the manifest, as cream rises on a pan of milk after all of it, apparently, has been skimmed off. Results are what count in practice, and it is certain that it is the objective signal of the shadow movements at the eye of the observer that shows what the state of refraction of the eye being examined is, wherever the target he is trying to see may be located, and whether he sees it clearly or not. If there is a real myopia, greater than the dioptric equivalent of the working distance, the shadow movements will be *against* the plane mirror. A part of this may be neutralized by taking a nearer working distance; then, by carrying the target farther back, provide the stimulus for less adduction and accommodation, by that means reducing the minus value indicated for the correction of the real myopia. The dioptric equivalent of the working distance, in plus, will then be greater than that of the target distance, and the subtraction of the former from the latter will give the minus result. That is, a 2 D. working distance (20″) from a 1 D. target distance (40″) is 1—2 = —1 D., the correction.

This is but a brief outline of the method. It appears to have been originated by Joseph Smith, optometrist, of Cambridge, Ohio. But his later collaborator, O. L. Altenberg, of Toledo, Ohio, has devised some interesting means of applying the method and assisted in its development. There are apparently a number of optometrists who have been persuaded to try the method, and those who could do so efficiently have found it gives most satisfactory results. It is especially valuable in astigmatic cases, as the different positions of the target at once give successively its neutralizing position for the principal meridians, and a clearly marked location for the axis of the cylindrical correction. When shadow movements are slow and indistinct, a supplementary lens may be employed to bring the point of reversal nearer to or forward of the observer's eye, thus accentuating them, or making the results more clearly visible to the operator. If the reader will bear in mind that this is a method of determining the full ametropia of the eyes by objective means, and not to enable the patient to see at any distance, and that the eye is refracted for the bright fundus reflex, and not for the target at all, he may get great advantage from its use, and perhaps become wedded to it as a quick and reliable method for measuring ametropia, as those who now practice it declare it to be.

It may appear to the superficial observer that dynamic methods that are not effective in arousing a desired action therefore fail, but this is not so. If the purpose is to stimulate a muscular action, or to relax it, the method succeeds although that effect fails. In presbyopia, one is unable to get the accommodative mechanism to be effective in convexing the lens beyond its limit; but the putting forth of an ineffective muscular action, if that is the purpose, is successful, even though it is ineffective in convexing the lens. In all of the ductions, the muscular action is involuntary, and even that may result in merely stabilizing the eyes, or one of them, in its position. If the eyes are fixing a target at any distance, and a prism is placed before one of them, that eye over which the prism is placed rotates to a new position. It has to, to continue to fix the target as seen through the prism. But the other eye remains fixed as it was, for it also has

to do that to continue to fix the object or target. Hence, there is muscular contraction of both muscles of the duction pair involved, although but one of the eyes rotates. So, in all dynamic methods, it is not the effectiveness in producing a motion that measures the direction and amount of the action, but the neuro-motor stimulus that the muscle gets, whether to rotate or effect a movement, or to prevent one, or to restrain it. Muscles act as "checks" to movements as well as to produce movement; and where there is a movement possible in any direction, there is a check and counter movement to restrain the first or produce the opposite movement, and this is as true of the accommodation and ciliary action as of any other.

It is possible that the discrepancy between the subjective focalization of the target for vision at the nearer distance, and the objective focalization of the fundus reflex at the observer's eye, may be due to the fact that the former is focalized at the rods and cones of the retina, at its posterior surface; while the light that is focalized objectively at the observer's eye is from the anterior surface of the retina, and slightly nearer the dioptric media, which would carry its conjugate to a greater distance from the eye. The retina is very thin but there are eight layers of nervous tissue between the two surfaces, so that a separation of even this small amount is in favor of putting the conjugate of the anterior surface farther forward, or nearer the eye of the observer than that of the rods and cones, the sensory visual field.

If that is the explanation of it, then by shadow testing we refract the eye for the non-sensitive anterior surface of the retina, instead of its sensory field of vision. The red that shows through in the fundus reflex is due to the transparency of the retina, as the vascular elements, the arteries and veins, are even farther back in the structure. Perhaps very few will ever discover or appreciate such a slight difference as might be made by so thin a layer of tissue as that of the retina, but very small distances are highly potential near the focus of a lens of any kind; and the nearer they are to it the more potential they are, especially in a high power lens like that of the dioptric media of the eye. A distance of 1/17 of a focal length, or 1 mm., makes a difference of 17 focal-lengths in its con-

jugate, or 289 mm. = about 11.5 inches from the anterior principal focus. But the thickness of the retina is very much less than 1 mm., and therefore its conjugate is placed at a greater distance. For .25 mm. it would be practically 1 meter.

CHAPTER XI.

Muscular Exercise.

If you see a young man, fresh from his morning bath, holding a pencil or other small object at reading distance from his eyes and, while his head is rigid, moving this target from right to left and up and down, or around in circles, while his eyes, to maintain fixation of it, rotate in their orbits; and a moment later he holds the target in a fixed position and makes the gyrations with his head, but maintains binocular fixation of the target by rolling the eyes in their orbits, you may say that he is a disciple of good old Dr. Taylor (peace to his memory) of South Dakota, who made a hobby of "oculo-didactics" and taught the system to the pupils of many public and private schools in his own and neighboring states. In his viewpoint, or from it, these exercises strewed the path of life of the one who practiced them daily with roses, cultivated alertness of movement, poise and grace of posture and motion, not only of the eyes but of the entire body as well.

As an optometrist, he appealed with some authority to school superintendents and teachers. He had a pleasing philosophy on the subject and would discourse upon it in an interesting way, as most people with a hobby are able to do. In later life he often entertained optical conventions with a discourse upon his methods, and the benefits to be derived from a system of "muscular exercise" of this kind, for quiet and steady eyes are symbolical of a quiet and steady mind; and alertness and quickness of movement of the eyes, and the cultivation of these powers, are reflexed to all the muscles of the body. On the other hand, any deformity of bodily movement or posture, such as a high shoulder or a slanting hip, or a wobbling walk or awkward sitting position, indicated the need of ocular muscle exercises. They tend to stiffen the flabby muscles and to relieve the rigidity that muscles acquire from non use. He has many disciples among optometrists today, and their numbers are apparently increasing. Even the president emeritus of the national association is one of them.

Methods of Exercise

There are two principal methods of stimulating the ocular muscles to action, or of relaxing them to the fullest. Optometry affords

every opportunity to use either or both methods, or to combine them. Briefly, these methods are as follows:

1. *The Natural Method.*

(a) While the patient is fixing the target at reading distance, it is moved from side to side, up and down, and circled or gyrated about.

(b) While the target is stationary, the patient makes the gyrations with his head, but maintains fixation of the stationary target.

2. *The Artificial Method.*

(a) While head and target are in fixed positions, lenses to relax or stimulate specific muscular action are placed before one or both eyes.

(b) Prismatic discs that cause an optical displacement of the target are placed before one or both eyes, and their values progressively increased or reduced.

The natural method alone affords a quite wide scope for muscular exercise, for by changing the direction of the target the version pairs of muscles may be successively called into play, or stimulated to action; and by changing its distance from the eyes, adduction or abduction, along with increased or reduced accommodation, is brought about. A distant target could not be easily changed in "direction" from the eyes, so as to stimulate the versions, but the patient's head, under the optometrist's direction or guidance, is easily manipulated as required, to call for any of the versions. But, since the limited ductions that can be exercised by the natural method require a near target, the version exercises may also be exercised for it. Let us consider a simple method for the latter exercise of the muscles with both the direction and distance of the target under control.

The Natural Method

This requires, for the near distance, a distinctive target that is visible at reading distance and for some distance farther away. Holding it at reading distance before the patient and asking him to read it,

he at once exercises, if he can, the required adduction to fuse the images on the retinae, and the accommodation required to make the images as clear as possible. As he may be slightly presbyopic, or have less than normal acuity of vision, different sizes of letters for different classes of patients should be provided. If he sees and reads the letters on the target card, he is assumed to be adducting and accommodating normally for the distance, although he may not be quite reaching the normal mark in accommodation. If there is any faintness to his vision at this distance, the target may be moved from 13 to 16 or even to 20 inches. The demand for adduction is thereby abated, and abduction turns the visual axes outward.

Assuming that he sees it clearly and easily at 20 inches, this position represents accommodation of 2 D. by each eye, and about 12△ of adduction. If the target is on the medial line of vision, there is normally no version exercised. We then direct the patient to hold his head firmly in that position, or not to turn it in any direction. The target is then moved as far upward as he is able to see it; then as far downward and then to the right and left. As soon as the patient understands exactly what you want him to do, he will do it readily. You then gyrate the target through various curves, moving it first in one direction and then in another, but maintaining the distance of 20 inches, or plane of a 20 inch distance. After a brief exercise of this kind, you ask him to look at a target with finer letters upon it, and bring it nearer to the eyes; and one with coarser letters and carry it farther from them. This stimulates successively positive and negative accommodation, and with it adduction and abduction of the eyes.

Having determined his range of good single vision, a medium target, or one with the medium sized letters upon it, may be given all of these different movements, up and down, to right and left, round and around, and brought nearer to the eyes and moved to a greater distance from them, thus calling into play all of the recti muscles, both in version and duction pairs. It isn't necessary to go to the limit in any of these movements. Comparatively slight, but more and more rapid ones, are preferable. A two or three minute period of this exercise will be tiring at first to both operator and patient,

but later to the patient only; and he will soon be able to give himself the exercise without assistance, but don't neglect to see that he does it under your observation. To vary the exercise stabilize the target at the vision distance, and have the patient make corresponding movements of the head, while he approaches and recedes from the fixed target. In this phase of the exercise, neck and eye muscles are simultaneously employed.

There seems to be no objective or natural way of stimulating the oblique muscles, except in co-ordination with the recti muscles, nor any way of observing or measuring the amount of their action. The eyes have no markings to indicate whether the vertical meridians are vertical or the horizontal meridians are horizontal. In appearance they are pretty much alike all the way around, or in all directions from the pupils. It would not be perceptible outwardly if one or both eyes were turned upon their anterio-posterior axes 5° or 20°, in the same or opposite directions, for they would still have apparently the same front. But, such a rotation of the eyes would rotate the retinae the same amounts, which would manifest itself visually or subjectively. We therefore have to depend upon artificial methods for exercising these muscles, and can only estimate the amount of the torsions or cyclo-ductions from subjective effects that are entirely relative.

Artificial Methods

These consist of the employment of material agents of any kind to interfere with, modify or alter the course of light in its propagation from the object to the eyes, such agents being placed directly forward of either or both eyes, so as to allow the light from the distant target to take its natural course up to that point. We may, in this manner, artificially reduce the volume of light entering the eye, or confine it to one meridian, as with the pin-hole or stenopaic discs, and this will affect the functioning of the muscles of the iris. We may use spherical or cylindrical lenses to affect the normal focalization of light upon the retinae, and thereby stimulate or quiet muscular action of the ciliary muscles. We may cause two entirely different images to appear upon the two retinae, and so deviate the

course of light to one or both of them as to cause them to occupy corresponding positions, thus enabling the visual sense by their related character, to fuse them into one, or to see two targets as though it were but one. We can so displace one or both images that they would be separated, thereby making the eyes see one object as two, and thereby stimulate such action of the extrinsic muscles as will place the retinae in the relative positions required for fusing the two images into one, or to cause fusion of the images.

The appeal is made directly to the visual sense, in all of these means of altering the normal or natural course of action; and our object is either to allay or subdue muscular action of some character by special muscles, or it is provocative of such action by them. In this way we exercise the muscles without altering the position of the target or changing its character. We know that the visual sense will "take alarm" at any interference with normal seeing, and at once, through its voluntary or involuntary motor-nerve agents, stimulate the muscular action that is required to neutralize, as far as possible, such interference. Muscular exercise is the alternation of contraction and relaxation of a muscle, not its steady contraction, nor its contraction to the limit of its power. Hence, by using low power agents for interference, and removing them quickly, a wide range of exercise can be given the muscles in a very brief period, provided our facilities for giving them are sufficient. A trial case and trial frames will answer, if there are no better means at hand. But up-to-date optometrists who give these exercises find it advantageous to have special facilities for giving them. A few simple devices are helpful to those who may not be provided with the more expensive means of giving these exercises. They can obtain these later, when their practice in this field has paid for a better equipment. The simpler devices referred to include, among others, the following:

Trial Case Devices

Even the batteries of spherical lenses positive and negative, may be employed for muscular exercise upon a distant target. Plus sphericals subdue positive, or incite negative, accommodation; minus

spherical lenses incite positive, or subdue negative, accommodation or ciliary action and relaxation. Alternation of imposing and removing them from before the eyes therefore is ciliary exercise. Placing the pin-hole disc before one eye, the other being covered, by reducing the volume of light incites dilatation of the pupil, or contraction of the radial muscles of the iris; while its removal by again flooding the eye with light, causes constriction of the pupil, or contracts the sphincter muscles of the iris, and relaxes the radials. An iris diaphragm, so mounted that there would be a place for it in the trial case, and it could be inserted in a cell of the trial frame, would improve facilities for giving exercises of this kind. The stenopaic slit, by rotations from 90 to 180, and vice versa, alternately exposes those meridians to incident light.

The battery of prisms in the trial case provide every facility for so deviating the light from the target, just before it enters the eye, as to put an immediate tension upon the muscle under the apex of the prism so as to rotate the eye and give its visual axis the direction required for the target in its displaced position, or apparently new direction from the eye the prism covers. But the other eye, uncovered, must maintain its fixation of the target, and therefore be restrained from turning with the eye before which the prism is placed. Hence, a pair of duction muscles are incited to action, whatever may be the position of the prism before either eye. Removing the prism at once allows such muscular action to subside, and this is muscular exercise of the pair or pairs of duction muscles so incited to action. This may not be the handiest way, and therefore a special mounting of a series of prisms, with their bases all in the same direction allows successively higher powers to be placed before the eye. But this is not an elegant device, and rather awkward to handle.

Risley Rotary Prisms

This consists of a pair of prisms of equal power, so mounted in a metal disc as to permit their rotation equally in opposite directions, and with a mechanism for so rotating them, having a handle that projects to the side, which is operated by twisting its head between the thumb and fingers. The handle also enables the operator

to place it in any desired axial position in a trial frame cell, and to rotate the entire device without disturbing the axial position in the cell. The prisms may be set at neutral by rotating them in the disc to the position in which the base of each prism is opposite the apex of the other. Then, by rotating them in the disc, base and apex separate, and the two apices and two bases rotate toward each other, finally coming together. In this position the prismatic power is that of the two prisms combined, or double the power of each. But, in their rotation, they successively add to the power of one direction, midway between the axes, or in the direction toward which their bases rotate, and this may be in either direction by opposite turnings of the prisms.

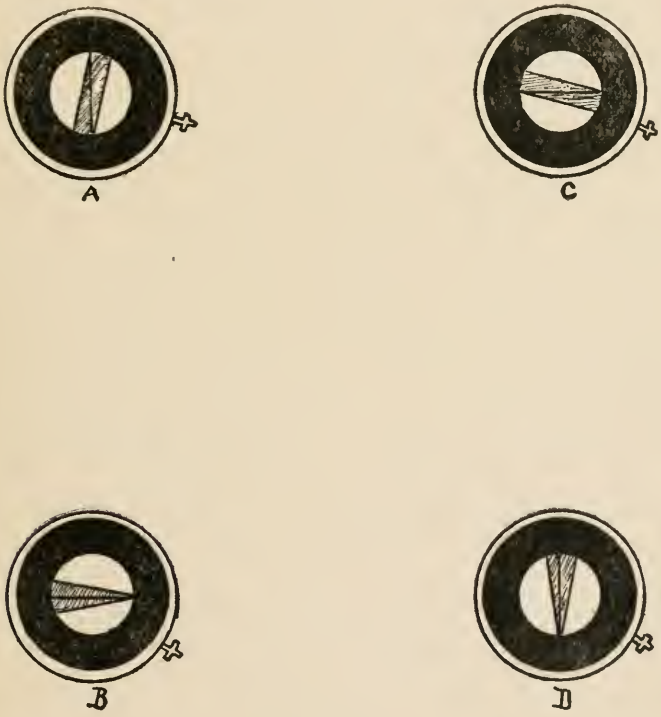


FIGURE 40.

The Risley Rotary Prisms: A, neutral position, for rotation to horizontal power; B, horizontal power, base in or out; C, neutral position for rotation to vertical power; D, vertical power, base up.

If a pair of 4△ prisms are mounted in the above manner, and the prisms are set at the neutral position, it may be placed with the base-apex lines of both at 90 in the rotary cell of the trial frame before the right eye. In that position, rotation of the prisms in the disc at once develops prismatic power at right angles to the neutral position, or at 180. In one direction of rotation this prism power is developed base-in before the right eye, in the other direction it develops power, base out. But before the left eye, in which the directions of the base, in or out, are opposite to those for the right eye, rotation of the prisms that develop prism power base in for the right eye develops prism power base out for the left eye. In using the Risley Rotary Prisms for the purpose of developing prism power, one needs to be sure of the effects of the rotations before the eye in front of which it stands, and especially if he uses two of these devices at once, one before each eye.

As to the power of the twin prisms in a Risley Prism device, the stronger the prisms the more rapidly rotation develops their power. A pair of 4△ prisms in such a mounting, starting from neutral, develops the power of but one of the 4△'s when the rotation carries them to the point where their base-apex lines are at right angles to each other, and it is on the line midway between them. Rotation of 90°, or from vertical to horizontal, develops the maximum power of the two prisms, the sum of the two, but along the same midway line between the two base-apex lines of the prisms. The development of prism power by rotation is, from the neutral position, at first very slow, for it is relative to the squares of the sines of the angles; and since the sines are fractional, their squares give a smaller factor than the sines. The sine of 30°, for instance (sin 30°) is .5, or ½ of a radius; but its square is but .25, and this is the factor of value. With the base or apex of a prism at 30° from neutral its power is .25 of that of the prism along the line at right angles to its neutral position. Each of the prism values follows the same rule. But these values are usually marked off on the Risley Prism device, and for the prisms it carries.

As low prism values may be obtained by slight rotations of strong prisms, the twin prisms of the Risley Prism devices are usually quite strong. But, for exercise purposes, it might be better

to have them of lower power. The object being the development of control by exercise, the weaker prisms that develop sufficient power and not too rapidly, ought to be preferred for the purpose. The full power of the prisms is only used to determine the maximum duction power of the muscles after a period of exercise. If the prisms are used in pairs, a pair of the Risley Prism devices, one before each eye, and are set neutral at 90 before each eye, to develop prism power, base in or base out, they are rotated in opposite directions. To rotate them in the same direction develops prism power base in before one eye, with prism power base out before the other eye, or makes the prisms neutral, so far as their effects in producing ductions is concerned. They will produce versions rather than ductions, for the bases will be in the same direction, both to the right or both to the left, but one in and the other out. The objection to a single device is that, since one eye only rotates back of the prism, the displacement appears to be in that direction only, and to the eye before which the prism stands. A slight turning of the face in that direction balances the duction, however.

There seems to be a good many optometrists who are stricken with the delusion that a prism before the right eye affects the muscles of that eye only, in a duction test. If that were really a fact the left eye might be covered with an opaque disc while testing the duction of the right eye; or, if prism power, base in, were developed before the right eye, prism power base out of an equal amount simultaneously developed before the left eye would not affect the right. In using the Risley Prism device before the right eye to determine the adduction power of the two eyes, 20° or 20△ of adduction may be found. If the same test is made with the device before the left eye, it will not be essentially different. But this does not mean that there is a total adduction power of 40△, but only of the 20△, as found and verified.

Rotary Cylinders

A simple method of exercising the oblique muscles is to employ two equal plus or minus cylinders and insert them in the rotary cells of a trial frame, one before each eye, with their axes, to begin with, parallel, as both at 90 or both at 180. To avoid involving the ac-

commodation for normal eyes, plus cylinders seem best. They should be of sufficient power to impair vision of lines under the axes of the cylinders, as either +6 or —6 is apt to do. If our target at 20 feet is a cross, with distinct vertical and horizontal lines, a pair of +6 cylinders, axes 180, will leave only the vertical lines clearly visible. If the two cylinders are then rotated together in the same direction. they will tend to slant the clear vertical line in the direction the cylinders are rotated. The visual sense will demand such action of the muscles as will resist this tendency, or produce a corresponding version of the eyes. As soon as the vertical line assumes that apparent slant, the version is unable to overcome the displacement and the muscles relax.

Turning the cylinders in opposite directions will tend to give the vertical line a double appearance, one line crossing the other. To this visual anomaly the visual sense opposes, or incites muscular opposition. This therefore results in cyclo-duction of the eyes, engaging either the two superior oblique muscles together, or the two inferior obliques. The actual appearance of the crossing of the lines indicates that the effectiveness of muscular resistance to the optical displacement of the lines is no longer adequate. Practice in this exercise will soon increase the efficiency of muscular resistance to the doubling of the vision, and represents increased control of the oblique muscles over the cyclo-ductions of the eyes. This exercise has been found beneficial, particularly in cases of oblique astigmatism. Dr. Savage of Louisville, Ky., is and has for a long time been its leading advocate. His book upon Ocular Myology gives a full account of his theories and methods of giving these exercises.

It is usually found that oblique astigmatism, when symmetrical, is not difficult of correction, and a patient with this sort of astigmatic obliquity usually accepts the cylindrical correction, and wears it with comfort. But if the oblique astigmatism is asymmetric, it is usually quite hard for the patient to become accustomed to wearing it. In all cases of oblique astigmatism, whether symmetric or asymmetric, cylindrical exercises such as here outlined, appear to be helpful. They tend to relieve the peculiar qualities of asthenopia that the optical, and therefore the visual defect causes. Primarily the purpose in all muscular exercise is to relieve asthenopic symp-

toms, muscular asthenopia it is called, in distinction from accommodative asthenopia, although one is as much muscular as the other. The real painfulness of vision is of a nervous, rather than a muscular character, for pain of any variety is of course of a nervous character. It is not the muscles that ache, but the nerves that stimulate them that are in distress.

The rotary cylinders have been elaborated into an instrument that corresponds to the above. This must not be confused with the rotary cross cylinders that are used for measuring or verifying the refraction of an eye. In the latter the double, or cross, cylinders, rotate axially like the Risley Rotary Prisms, both being before one eye, and having a neutral relative position, and developing cylindrical power by their rotations in relation to each other. In the cylindrical phorometer a pair of equal cylinders are mounted binocularly for rotation in the manner above described. Their purpose is to give exercise to the oblique muscles, and violations of fusion of such a character that the oblique muscles alone are able to overcome the diplopia produced.

The Amblyoscope

This instrument is a modification of the stereoscope of former days, an instrument that, with the advent of the "movie" has become antiquated. The Amblyoscope has a binocular eye piece, and the two channels for the admission of light to the right and left eyes separately are so hinged together as to enable the operator to converge or diverge them. There is a prismatic pair of lenses before the eyes of the correct power to neutralize normal accommodation and convergence for the distances. But there is a separate target for each eye, the same as in the stereoscope, which are made visible by direct or trans-illumination. The targets are usually two pictures of separate parts of an entire object, such as a bird in a cage, a man and a horse, a person and his hat, a boy catching a ball, etc. There is this difference, that the bird is not in the cage, the man is not on the horse, the hat is not on the man's head and the ball is not in the boy's hands.

By the adjustments of the binocular tubes through which the light from these targets come to the eyes separately, the two retinal

images are brought together. At the right point of adjustment the bird takes his position in the cage, the man is on the back of the horse, the hat takes its place on the head and the boy catches the ball. That is, the two really distinct targets are "fused" into one, so that two pictures are seen as one. The tubes may be so adjusted that a person with strabismus and binocular diplopia may be made to see singly. When a child is in this condition, as often happens, and by the use of the Amblyoscope, the bird is put into the cage or the man is put upon the horse's back, the muscles of the eyes will resist any adjustment that tends to separate the two pictures, or to break up fusion of the images. The effect of muscular exercise of this kind is to so develop the fusion sense that the muscles of the eyes will resist separation, and diplopia will be eliminated. This is the first step in restoring the eyes to normal single vision, as that is essential before the tendencies of the eyes to deviate abnormally can be attended to, or the muscular imbalance be considered and treated, optically or surgically.

If the Amblyoscope possessed no other utility than that of cultivating the "fusion sense" in strabismic children, it would still be a valuable instrument for the optometrist to possess. It affords means for exercising the muscles that are involved in exercising the ductions required for the fusion of the images. Under its manipulations any person whose muscles are in normal balance will feel the strain that it puts upon the muscles to maintain fusion, and that is of course muscular exercise. These qualities make it a dynamic phorometer of special value, although it is not advertised as such. It is an ingenious way of putting the principle of the stereoscope to practical use in the development of control of the muscular functions of the eyes. The writer remembers to have seen a crude device of this kind in the office of one of the leading optometrists of Indiana, now on the state board of optometry, which was used as a means of determining the relative influences of the different muscular functions of the eyes upon each other. Though simply constructed, it was expected that the device, which had advantages even greater than the amblyoscope, would some day be on the market in more substantial and elegant form. But that was ten years or more ago, and it has not yet appeared. There are a good many valuable ideas that

never get farther than this, and for the obvious reason that they may conflict with some less ingenious device already being manufactured and sold, and they are therefore frowned upon by the optical trade, with whose instruments they would come in competition. In time they may be rediscovered under happier circumstances.

The Phorometer

A more elaborate instrument for testing muscular balance, and giving a course of training of the muscles, one that embodies all of the different means we have described under this subject, is the Phorometer. It may be described as an elaborated trial frame, for it provides all of its facilities in adjusting it to different patients, that a trial-frame has, and many more. It is in fact a phoro-optometer. It is usually mounted upon a stand or bracket, and may be swung into position pivotally, and then adjusted in height, level and pupillary width, bridge, etc., to the patient. As side parts there are one or two Maddox rod discs that are swung into position from the side. A single or two of the Risley Prism devices are similarly available. The trial case lenses may be inserted in special cells provided for them, or be mounted in circular discs that rotate them before the eyes, thus providing any lens value that may be required for either or both eyes.

Those who have one of these instruments complete make it serve all of these purposes, both that of the trial-frame and the phorometer. They are usually finished in black enamel or lacquer, or in a nickel finish for some of the adjustable parts. These give the instrument an elegant appearance, which has much to do with their impression upon the patient. There are several makes or designs of an instrument of this kind, each having special advantages and facilities that cannot be individually discussed. It is for the buyer of one of these instruments to make his own selection, weighing their respective merits as they are demonstrated to him by a sales representative. Optometry has been materially advanced by the class of instruments furnished by the manufacturers of these and other instruments, and one may consider that he is contributing to the general advancement by having and operating one of them. They may

be bought in different degrees of elaboration, like an automobile, so that one may decide the matter for himself as to the fullness of the equipment and the amount of his investment in it.

Genothalmic Refractor

This newest instrument, though named as above, is really an Opto-Phorometer. That is, while embodying facilities for measuring the refraction of the eyes, it also has the facilities for measuring and exercising the muscles. It is suspended before the eyes, which facilitates adjustments. The cylindricals are also nearest the eyes, the spheres in front. It is the "final word" in instruments of this kind, and the optical company who are putting it on the market warrant that it will be as near perfection for its purposes as it can be made.

DeZeng Phoro-Optometer

This was the first instrument of its class to appear and it has always held a prominent place in the equipment of the up-to-date practitioner. The facilities of this instrument have already been discussed in detail, therefore do not require repetition here. Suffice to state that long experience of the manufacturers in developing it has made it an instrument of precision.

The Woolf Ski-Optometer

The significance of the prefix in this title is the use of it for shadow testing the eye, or for putting the required lenses before the eyes in shadow testing. It has a special system for changing the values of the lenses, and also for placing cylinders in any axis, before the eye being tested. In other respects it is similar to other phorometers. One needs to see it demonstrated to appreciate all of its superior features.

General Remarks

What may be done to relieve the eyes, or to relieve suffering humanity of eye-strain, as the primary cause of many organic disturbances and symptoms, by muscular exercise through the employ-

ment of lenses, prisms and natural means of inciting the muscles to action, is still a prospect rather than an accomplishment.

There are, of course, many different ways of trying out the eyes to determine their true muscular condition. We have only given a few of the more important ones; for the others embody the same principles and are used in the same way. The optometrist may choose between the different devices and methods, using that method that he seems to obtain the best results from. There are now many who are working out systems for this purpose. Their experiences appear from time to time so that one must keep in touch with current literature on the subject to be really up to date. But first of all he must be grounded in the fundamental principles, so as to be able to read the signs intelligently, and to make his remedy apply to the case in hand.

Oculo-Refractive Cyclopedia and Dictionary—*By Thomas G. Atkinson, M. D. Complete, concise, simple, profusely illustrated. Price, $5.00.*

Optical Shop Practice—*By W. W. Merritt. Thorough treatise on making of lenses, fully illustrated. Price, $2.00.*

Business Side of Optics—*By Roe Fulkerson. Invaluable to the practitioner desiring to build up his clientele. Price, $1.00.*

Transpositions and Tables—*By Edward J. Lueck. Everything tabulated already for you. Price, $1.50.*

Text Book of Iridiagnosis—*By J. Haskell Kritzer, M. D. Dealing with pathological and functional disorders in the human body indicated by abnormal lines, spots and discolorations—the book you have wanted. Price, $5.00. Also Wall Chart of Iridiagnosis (32 colored plates of the iris and enlarged "iris", all in colors). Price, $2.50. Text Book and Chart, $7.00.*

FOLDERS

Interesting Facts Concerning Your Eyes—*One of the most popular folders ever used by the optometrists. An excellent business puller. Per thousand, with your imprint, $7.50.*

New Wrinkles—*Another fine folder widely used. Shows that wrinkles frequently indicate need for glasses or else (for those already wearing glasses) different lenses. Per thousand, with your imprint, $6.00.*

Meissner Record Cards—*Standardize and systematize your practice. Used all over the United States. Per thousand, $4.00.*

Published by

The Professional Press, Inc.

17 No. Wabash Ave. *CHICAGO*

RETURN TO **OPTOMETRY LIBRARY**
490 Minor Hall 642-1020

LOAN PERIOD 1 HOME USE	2	3
4	5	6

ALL BOOKS MAY BE RECALLED AFTER 7 DAYS
RENEWALS MAY BE REQUESTED BY PHONE

DUE AS STAMPED BELOW

UNIVERSITY OF CALIFORNIA, BERKELEY
FORM NO. DD 23, 2.5m, 12/80 BERKELEY, CA 94720

RE 731
R6
1922